Energy+Environmental Economics

Storage Cost-effectiveness

CPUC Storage OIR Workshop
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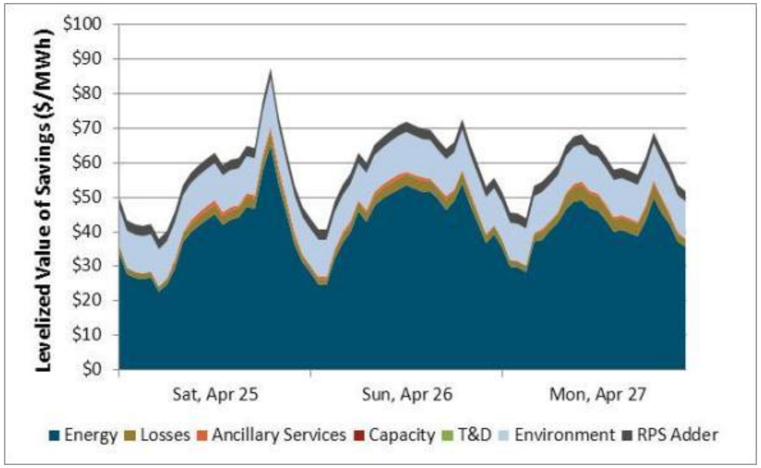
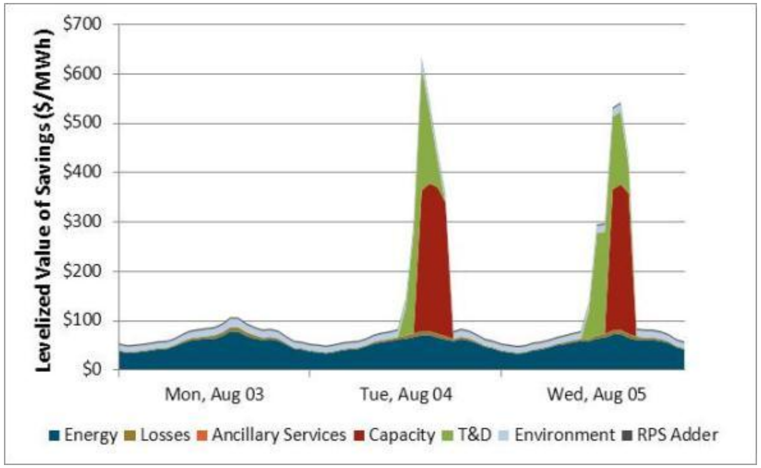
http://goo.gl/ZeZCM

INTRODUCTION

Today We Have CPUC Avoided Costs

Three-Day Avoided Cost Snapshots



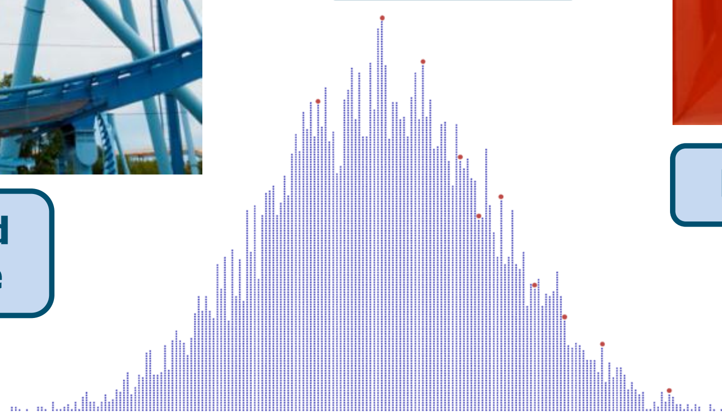


- Energy
- Losses
- Ancillary Services
- Capacity
- Transmission & Distribution
- Environment

But, Storage Can Do More…

Fast and Flexible

Modular



Option Value

Back Up

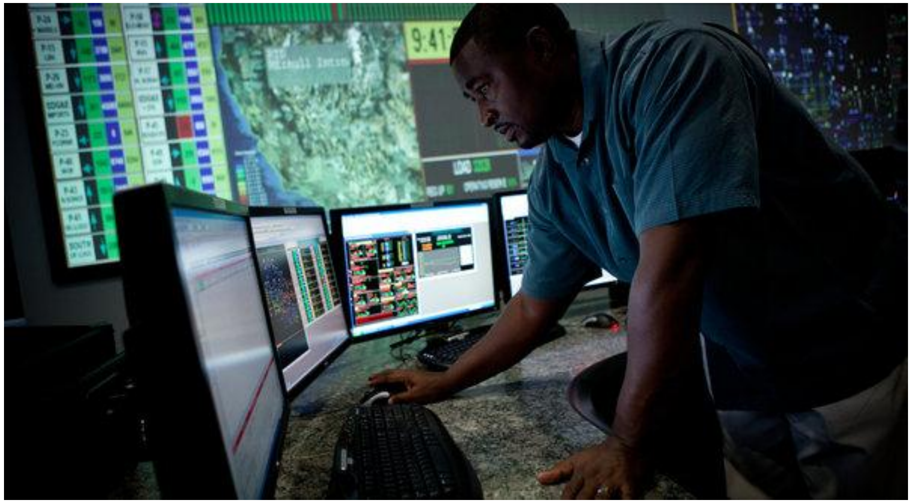
Environmental

While Also Bringing New Challenges

Proving Performance

Limited Energy Resource

Systems Integration

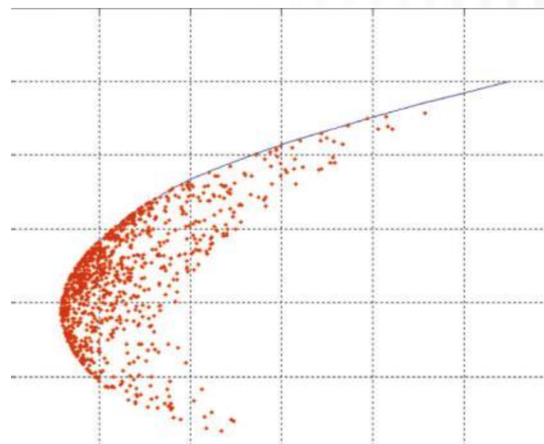


So What is a Storage "Benefit"?

+ **Direct Benefits**
  - Providing a specifically defined service
  - Quantifiable revenue or avoided costs
+ **Secondary Benefits/(Costs)**
  - Arise from grid impacts, but do not directly drive storage operation
  - Can be monetary (system production costs) or non-monetary (GHG emissions)
+ **Policy Benefits**
  - Facilitate meeting policy goals (e.g. GHG, Renewables)
+ **Renewable Integration is not a benefit!**

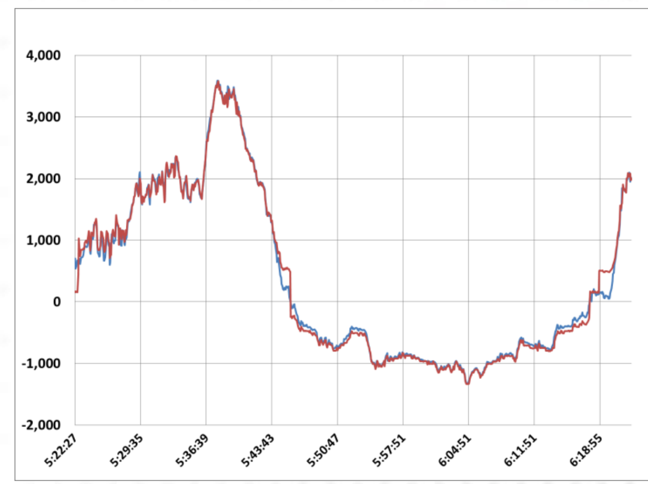
And How Do We Model Them

Properly Stack Multiple Benefits



Incorporate Storage in Larger Portfolio Analysis

Acknowledge Uncertainty with Sensitivity, Scenario and Monte Carlo Analysis



Accurately Model Resource Dispatch

Our Proposed Path Forward

+ Energy Storage Cost-effectiveness Methodology and Tool

+ Illustrative Energy Storage Use Cases

+ Evaluating Energy Storage in Resource Planning

EPRI COST-EFFECTIVENESS ANALYSIS

The Electric Power Research Institute (EPRI)

- **Independent, non-profit, collaborative research institute, with full spectrum industry coverage**
  - *Nuclear*
  - *Generation*
  - *Power Delivery & Utilization*
  - *Environment & Renewables*

- **Major offices in Palo Alto, CA; Charlotte, NC; and Knoxville, TN**

Principles of EPRI Energy Storage Cost-Effectiveness Methodology

- Technically defensible
- Focused on grid requirements and consider alternatives to storage
- Invest analytical resources in deeper understanding of high value use cases
- Avoid double-counting of benefits and separate direct from incidental benefits

EPRI Storage Cost-Effectiveness Methodology

Step 1a: Grid Problem / Solution Concepts

Step 1b: Grid Service Requirements

Step 2: Feasible Use Cases

Step 3: Grid Impacts and Incidental Benefits

Step 4: Energy Storage Business Cases

Step 1a: Problem / Solution Concepts

Determine a Problem or Potential for Improvement and Determine if Storage can Help

What is the grid operational or planning problem?

Defined

Can energy storage help?

Yes

GO TO

Step 1b

No

STOP

Step 1b: Define Grid Service Requirements

Define the problem and minimum solution, technical requirements, and the revenue or cost of best alternative solution.

Define solution technical criteria → Convert to energy storage requirements → Define solution value → Defined? GO TO Step 2

Step 2: Feasible Use Cases

Combine Grid Services into Use Cases with Dispatch Hierarchy to evaluate potential cost-effectiveness

Assess anchor service → Define compatible use case → Time-series dispatch / cost-effectiveness

Cost-effective or nearly so? → GO TO Step 3

Not? → Re-visit

Step 3: Understand Grid Impacts and Incidental Benefits (Costs)

After finding cost-effective use cases, assess impacts and incidental benefits or costs to energy storage deployment.

Simulate Baseline Scenario(s) – i.e. No Storage

Simulate effects of storage deployment scenarios

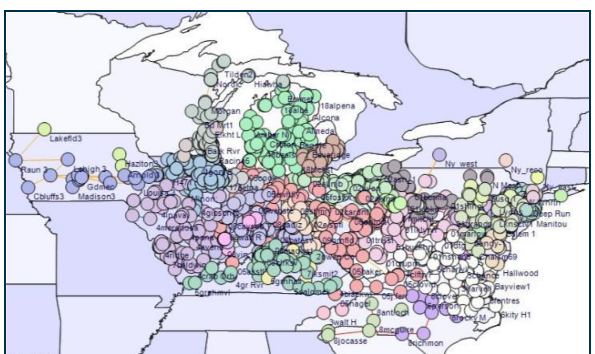
Assess additional costs / benefits of storage

Net benefit for society?

GO TO Step 4

Net Cost?

Re-visit

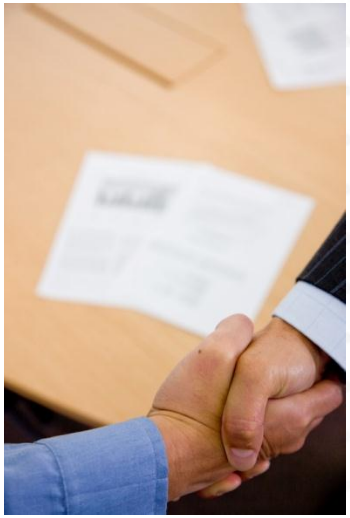


Step 4: Assess Energy Storage Business Cases

Assess policy scenarios and apply regulatory and business model realities to use-case cost-effectiveness assessment

Compelling business case?

Define Scenarios → Stakeholder Financial Analysis → Deploy



ENERGY STORAGE VALUATION TOOL

What is the Energy Storage Valuation Tool (ESVT 3.0) ?

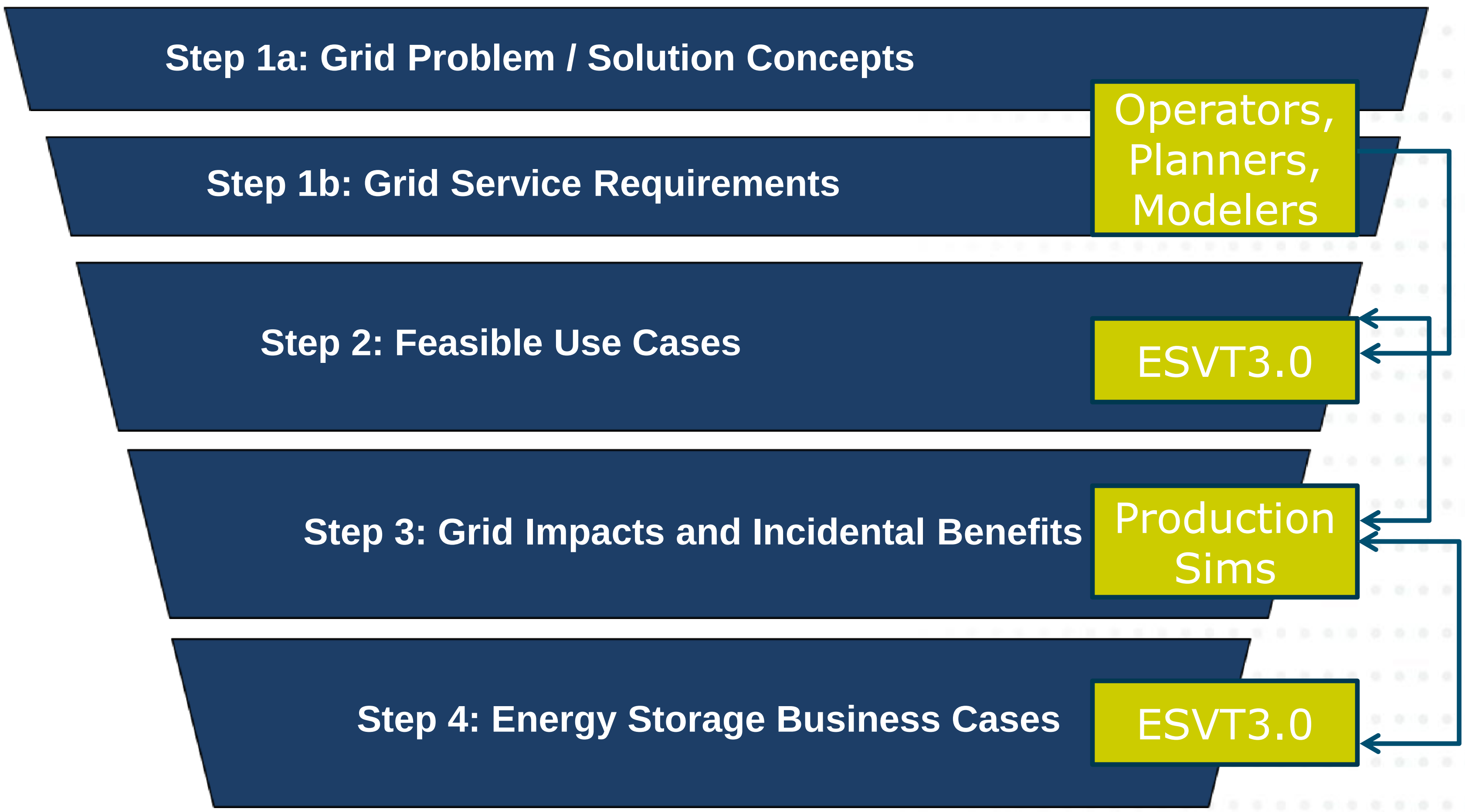
Transparent, user-friendly, cost-effectiveness tool to assess and communicate energy storage use-case and business case potential at specific sites.

- Includes pre-loaded defaults for energy storage service requirements, prioritization, values, technologies
- Customizable storage project lifecycle financial analysis
- Simulates technical potential of storage with service combination (use case) hierarchy
- Full electric system scope of services/benefits: Generation, Transmission, Distribution, Customer
- Transparent model approach with Analytica™ software - model including influence diagrams

Tools Used to Model Storage

Scope	Long-Term Planning	Reliability Modeling	Grid Operations	Distribution Planning	Technology Screening	Storage Cost-Effectiveness
Focus	Long-term resource needs	Reliability and Flexible resource needs	Near-term trans. grid resource needs	Near-term dist. grid resource needs	Screen technology and service combinations	Making and justifying storage investment decisions
Goals	Minimize cost and risk of resource portfolio	Manage variability, uncertainty and forecast error to meet reliability goals	Least-cost economic dispatch with reliability/ transmission constraints	Least-cost planning to meet reliability and tolerance thresholds	Identify promising technology/ services combinations	Evaluate expected NPV costs and benefits of storage investment
Framework	Portfolio Planning	Sub-hourly (<5 minute) dispatch	Production Simulation	Power Flow	Heuristics/ screening Analysis	Hourly dispatch
Examples	NESSIE, RETScreen, NEMS	LOLP Kermit GE-MARS	PLEXOS, UPLAN, GridView, PROMOD, Ventyx, GE-MAPS	HOMER, CYMEDist, OpenDSS	ES-Select	EPRI ESVT
Core Strengths	Evaluate range of future, regional scenarios and resource portfolios	Short time scale dispatch for LOLP, LOLE, frequency regulation, load following and ramp	One year system dispatch with zonal/nodal model of regional grid, including market price effects and unit commitment	High resolution power flow, Volt/VAR and fault analysis for specific grid configurations	Scoping analysis of a wide range of technologies and services	Lifecycle financial and cost-benefit analysis from owner/operator and societal perspectives

ESVT in the EPRI Cost-Effectiveness Methodology



ESVT 3.0 Informed by Multiple Utility Test Cases

+ SDG&E (CA) – Distribution investment deferral potential at a planned demonstration site
+ SMUD (CA) – Industrial customer based storage for demand charge management with PV
+ Salt River Project (AZ) – Investigating a transmission investment deferral opportunity
+ Salt River Project (AZ) – Customer premise storage with multiple residential tariffs with PV
+ Southern Co (AL) – Distribution energy storage for voltage support, backup power, and investment deferral
+ FirstEnergy (NJ) – Distribution PV impact mitigation and investment deferral

PEAKER USE CASE

Peaker Services

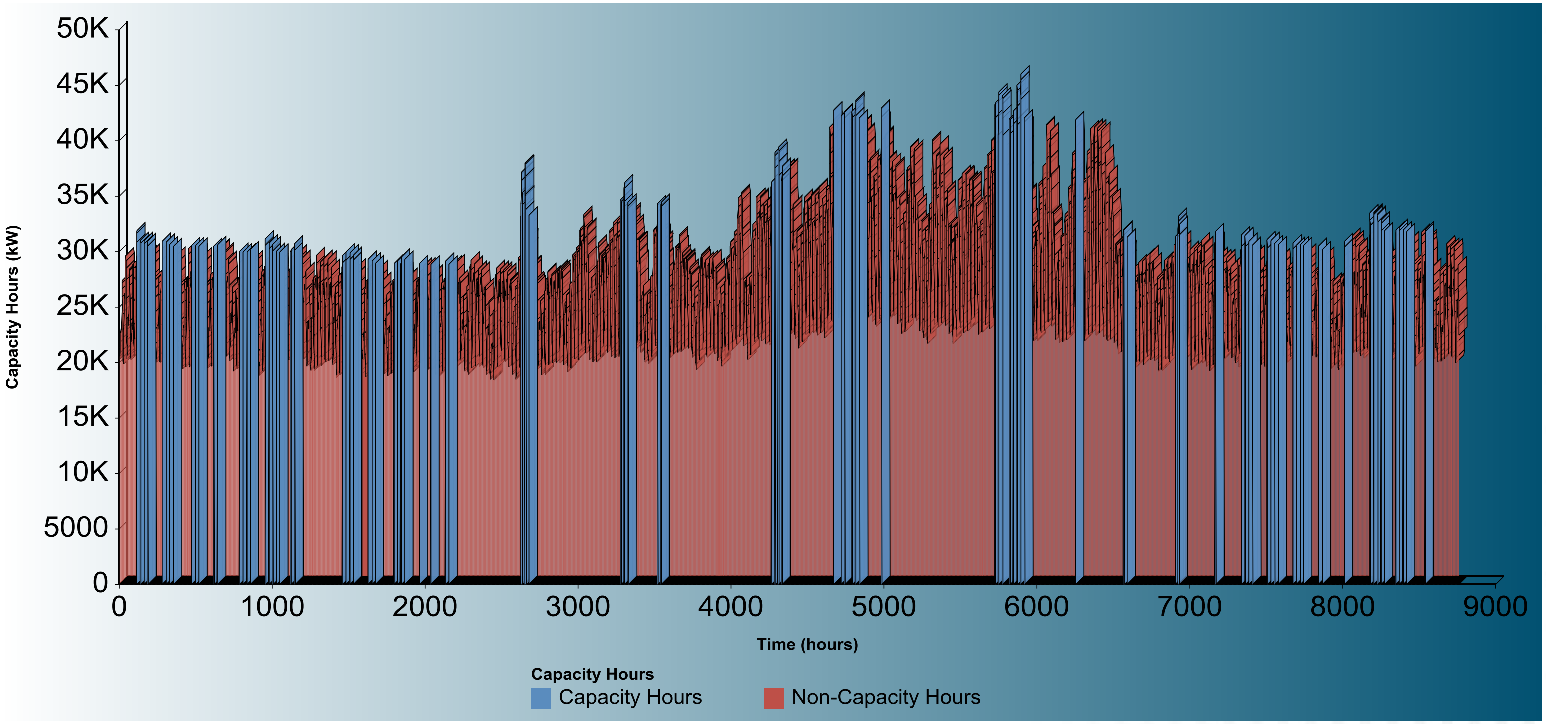
- Storage used similarly to a conventional capacity resource
- Offers capacity into CAISO market on system peak days
- Earns energy and ancillary services revenue

Capacity Value Approaches

- **Absolute: Capacity service is highest priority. Storage must be full at beginning of identified capacity hours**
  - Capacity MW based on 4 hour deliverability (user defined)
- **Derate: Storage makes best effort to be available during capacity hours. Storage capacity MW is derated based on actual availability**
  - Storage devices with limited state of charge would receive more of a capacity derate due to their inability to discharge over a sustained system peak.

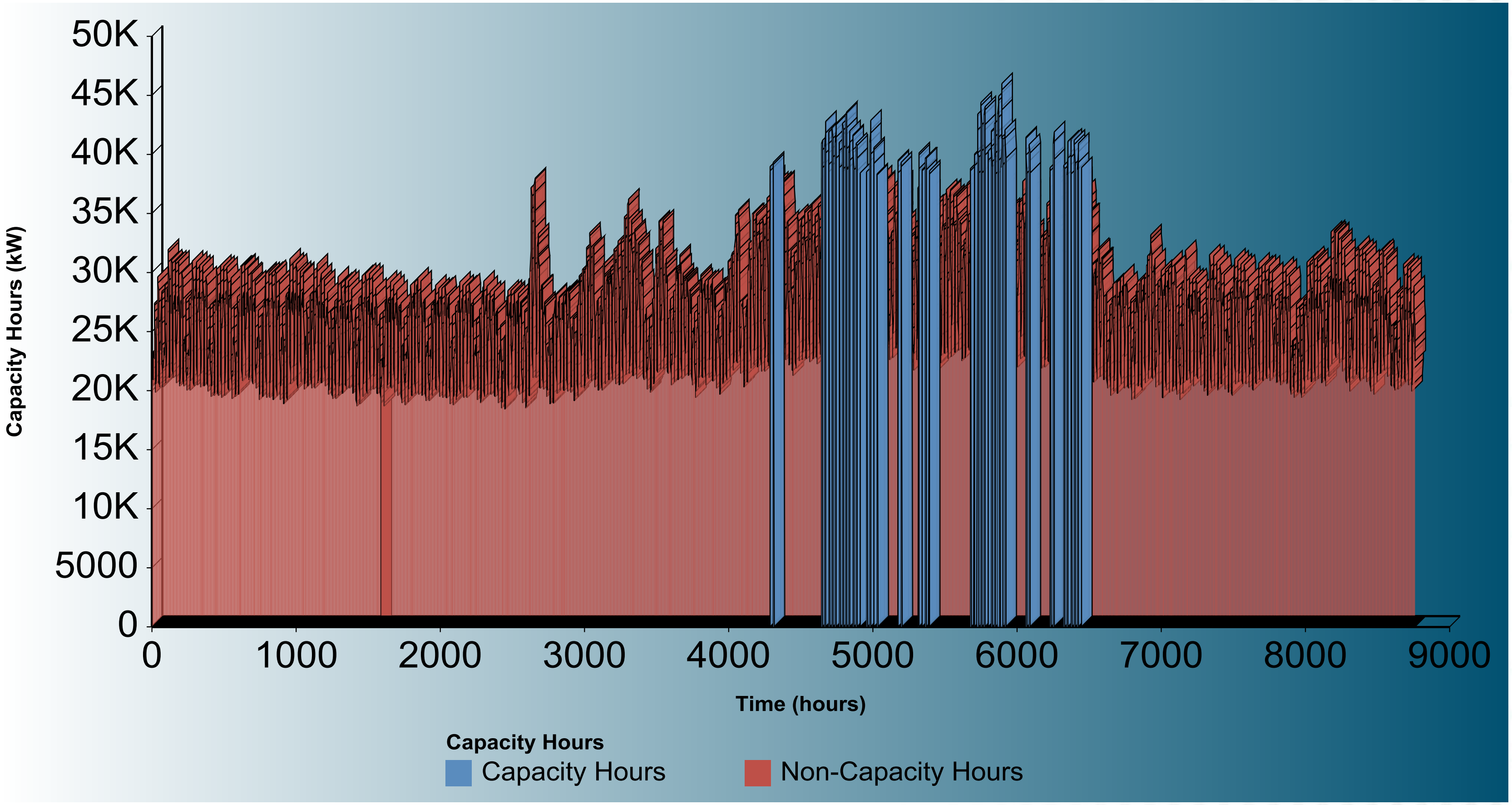
System Capacity Requirement

- Top 20 load hours of each month are defined as capacity hours

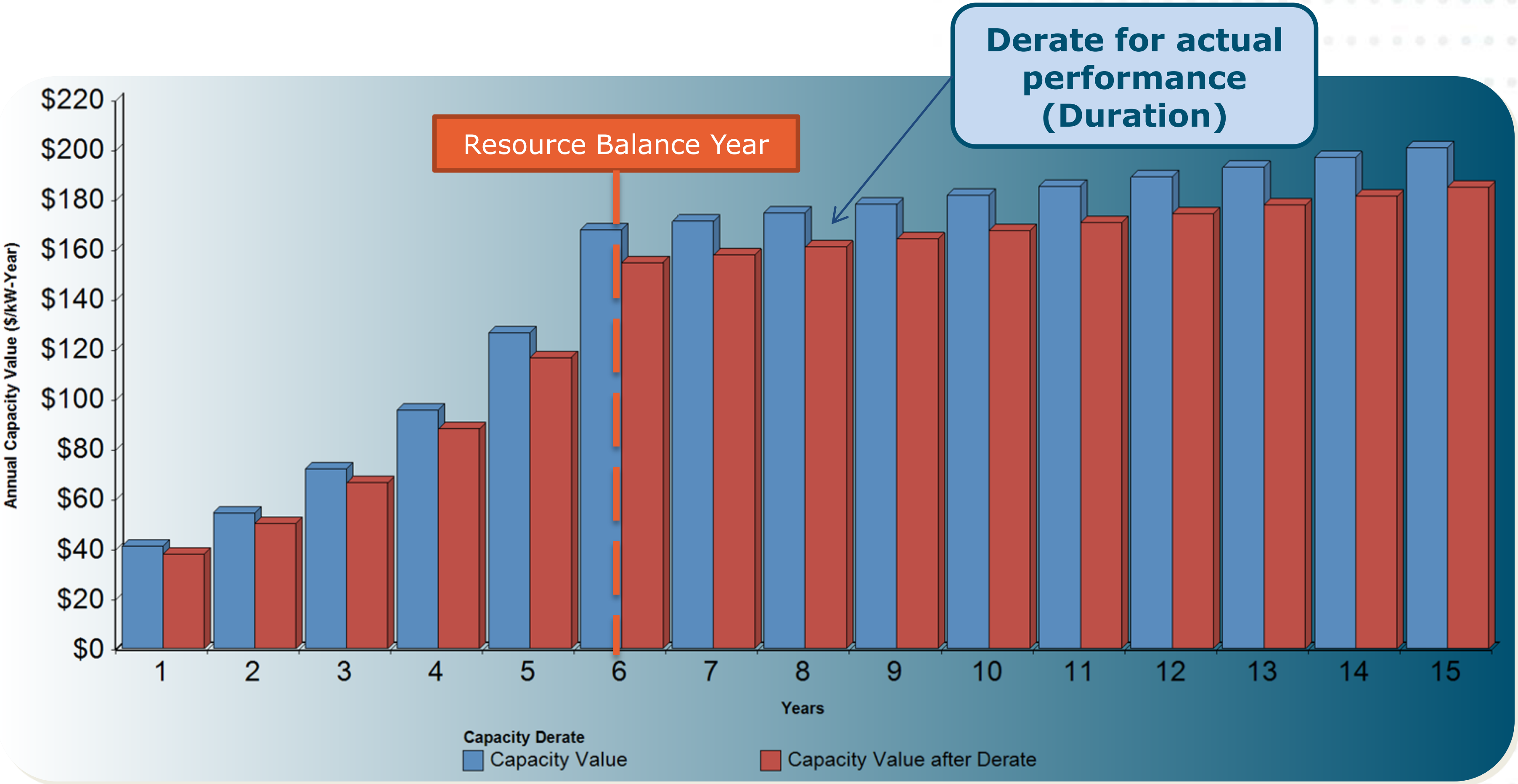


System Capacity Requirement Alternative

+ **Top 250 load hours of the year**



System Capacity Revenue



Peaker Participates in Energy and AS Markets Remainder of Year

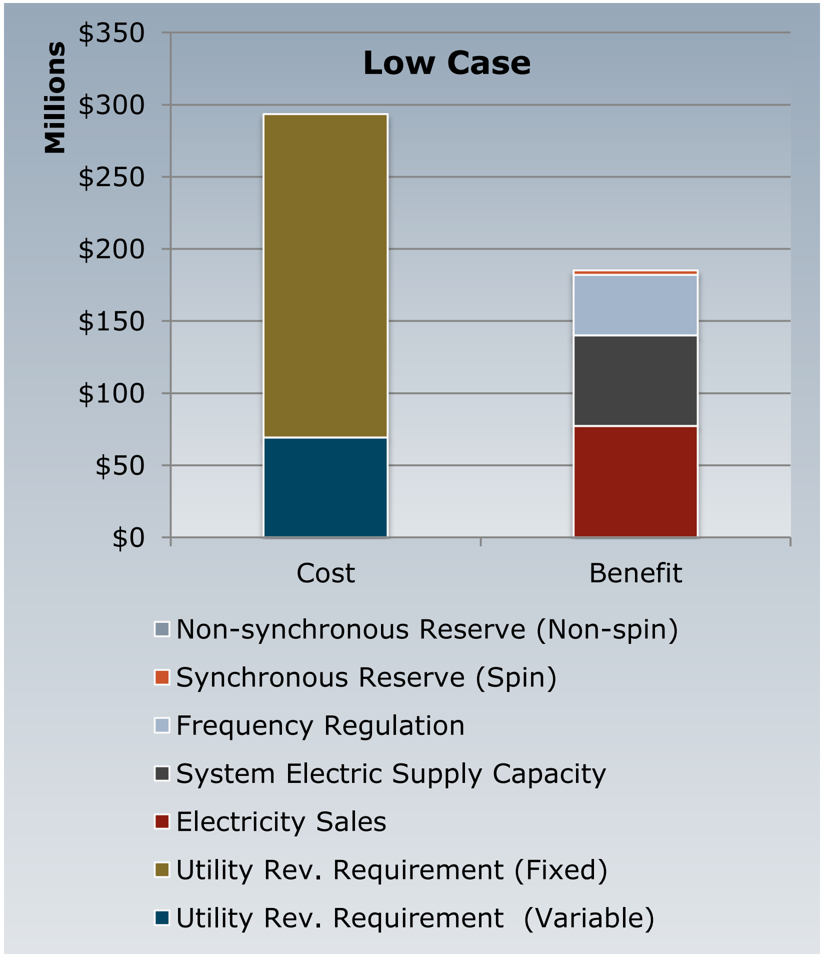
- **Storage Market Dispatch is optimized on a daily basis**
- **Co-optimize bidding in DA Energy, Regulation, and Spinning Reserve Markets**
- **Market Bidding is informed by current CAISO rules and storage characteristics including:**
  - Regulation Energy Management (REM)
  - Expected deviation from setpoint based on CAISO data
  - Efficiency Curves (CAES and Pumped Hydro)
  - Resource Adequacy requirements

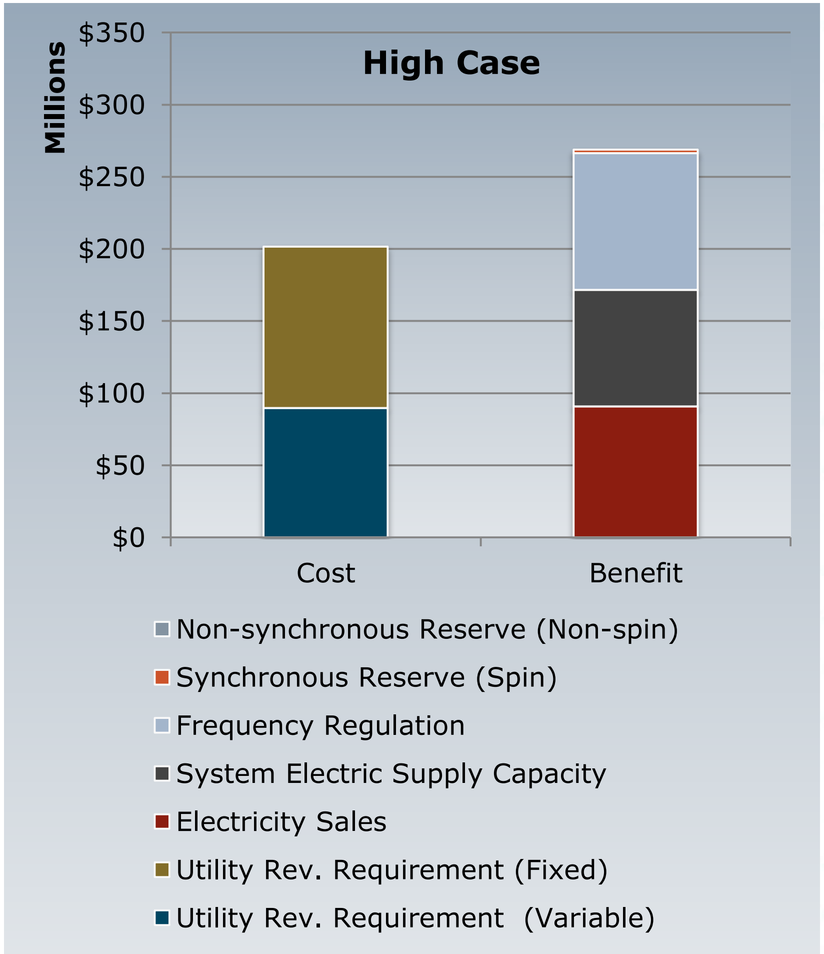
PEAKER USE CASE SCENARIOS

Low/High 2020 Scenario Assumptions

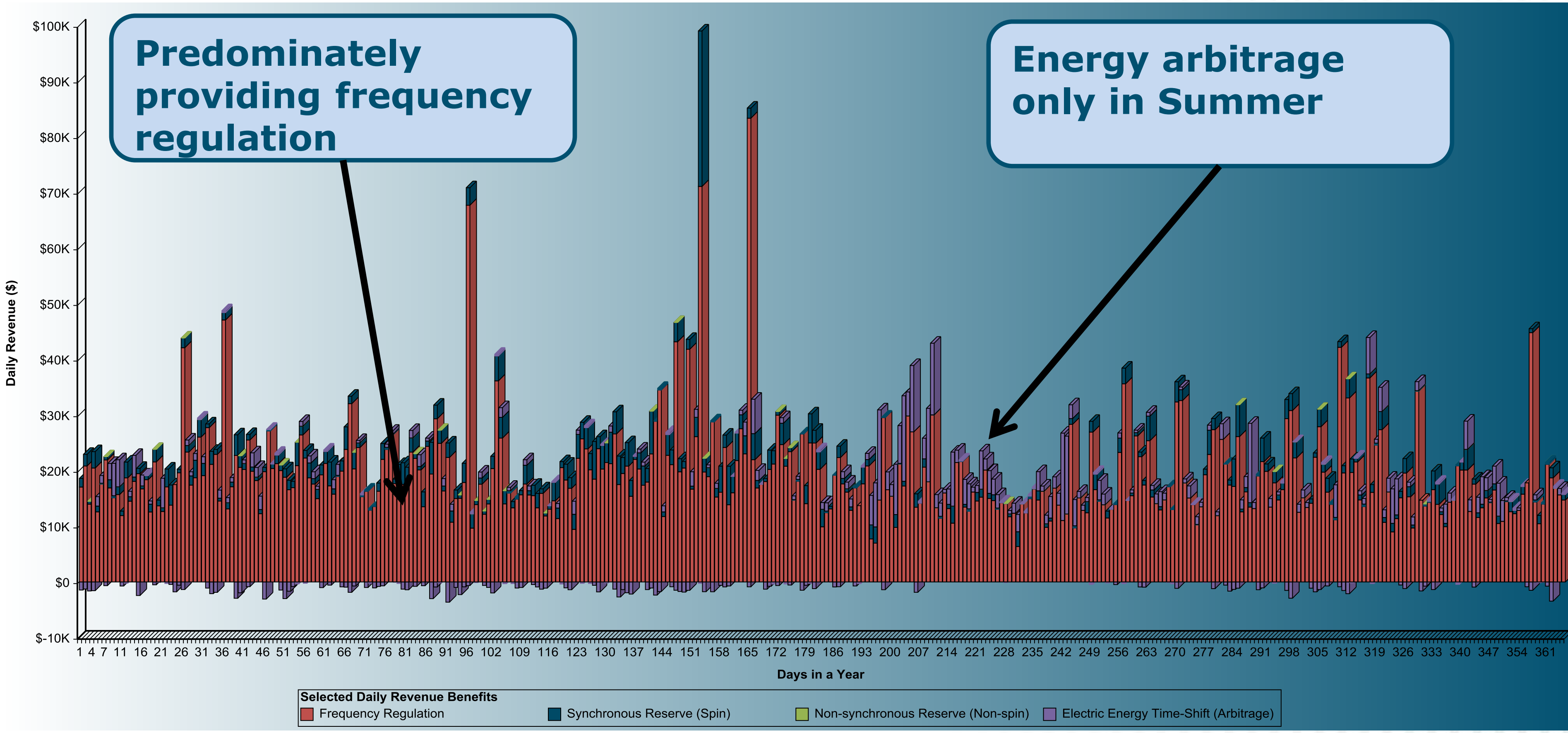
Inputs	Low	High
Storage System Installed Costs ($/kWh Installed)	**$1,000**	**$500**
Useful Life (Years)	15	15
Discharge Capacity (kW)	50,000	50,000
Discharge Duration (Hours)	4	4
Roundtrip Efficiency	90%	90%
Variable O&M ($/MWh)	$1.40	$1.40
Energy ($/MWh)	$63.75	$63.75
Frequency Regulation Up ($/MW)	**$4.88**	**$9.76**
Frequency Regulation Down ($/MW)	**$4.31**	**$8.63**
Synchronous Reserves ($/MW)	**$3.53**	**$7.05**
Non-Synchronous Reserves ($/MW)	**$0.52**	**$1.04**
Resource Balance Year	**2025**	**2020**
Cost of New Entry ($/kW-Year)	$152	$152

Peaker Cost/Benefit Comparison

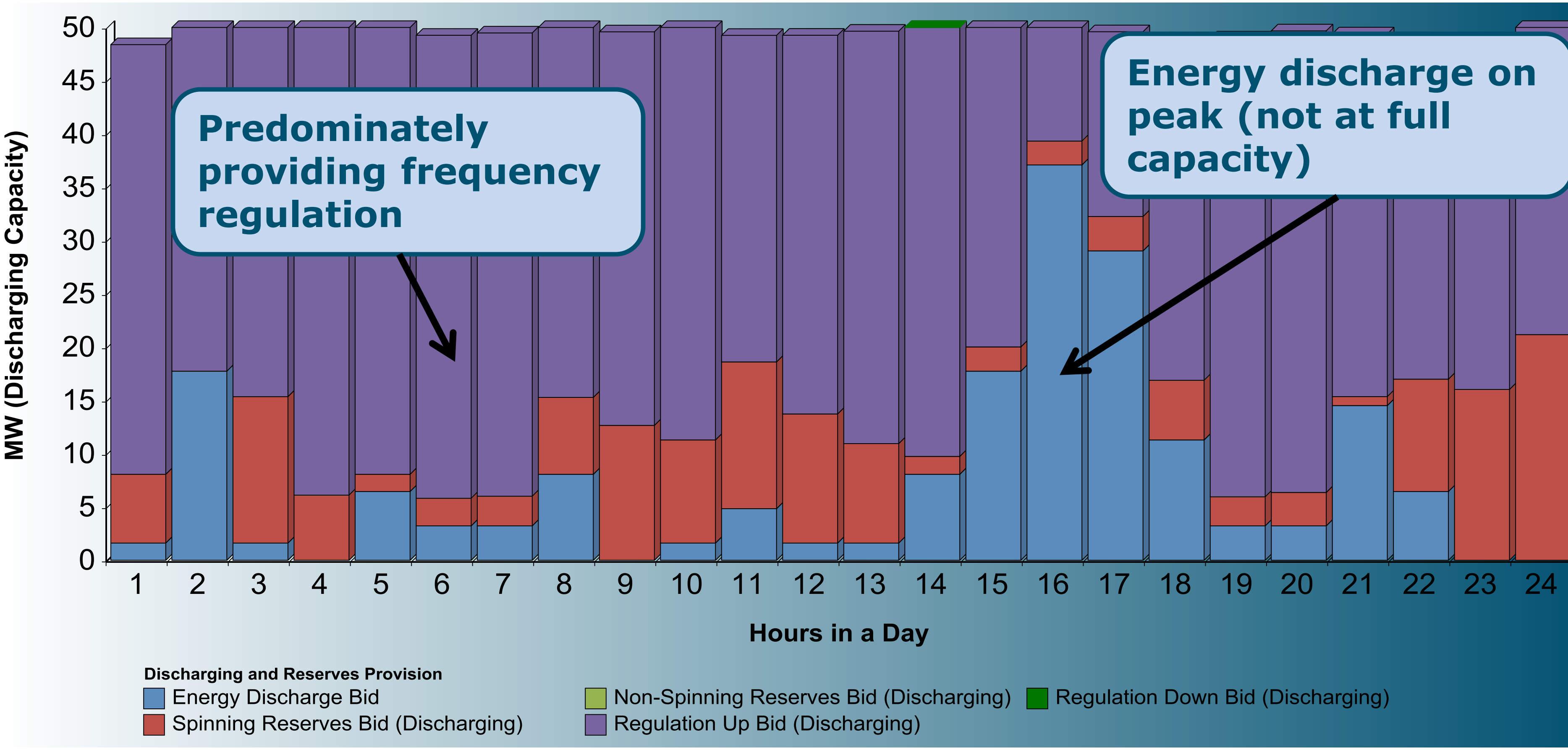




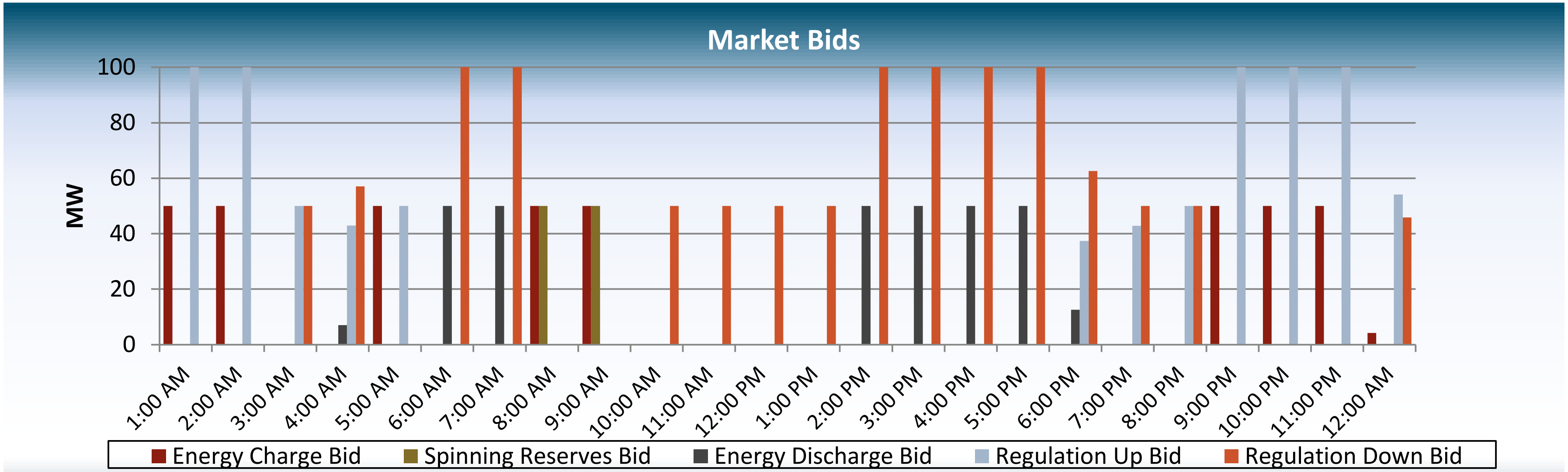
Annual Revenue by Market

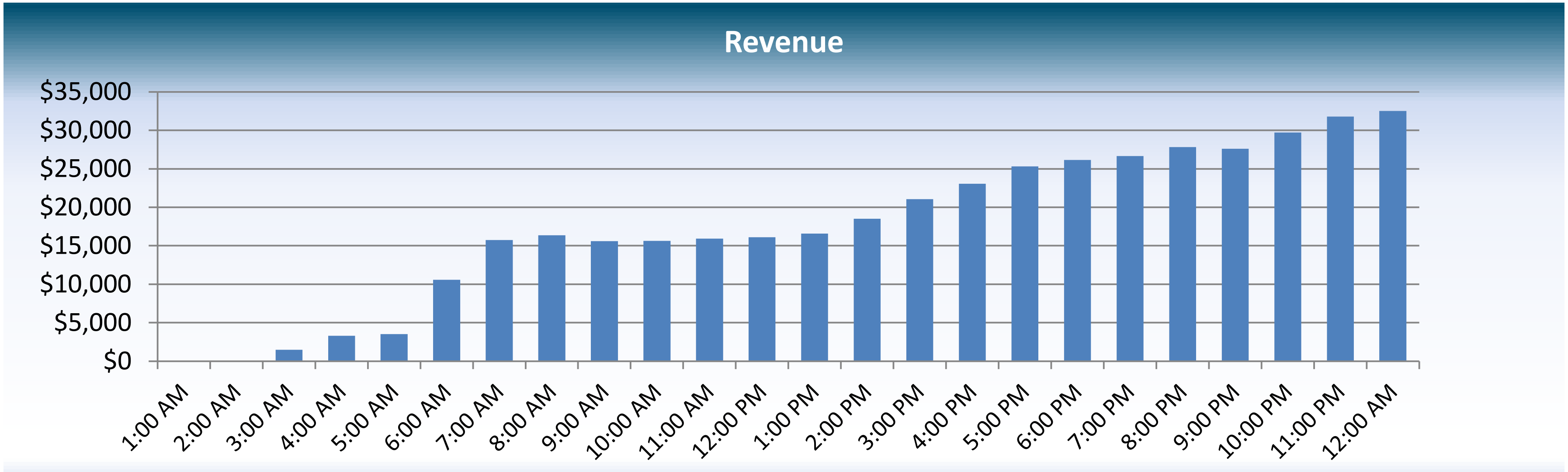


Daily Dispatch by Market (July)



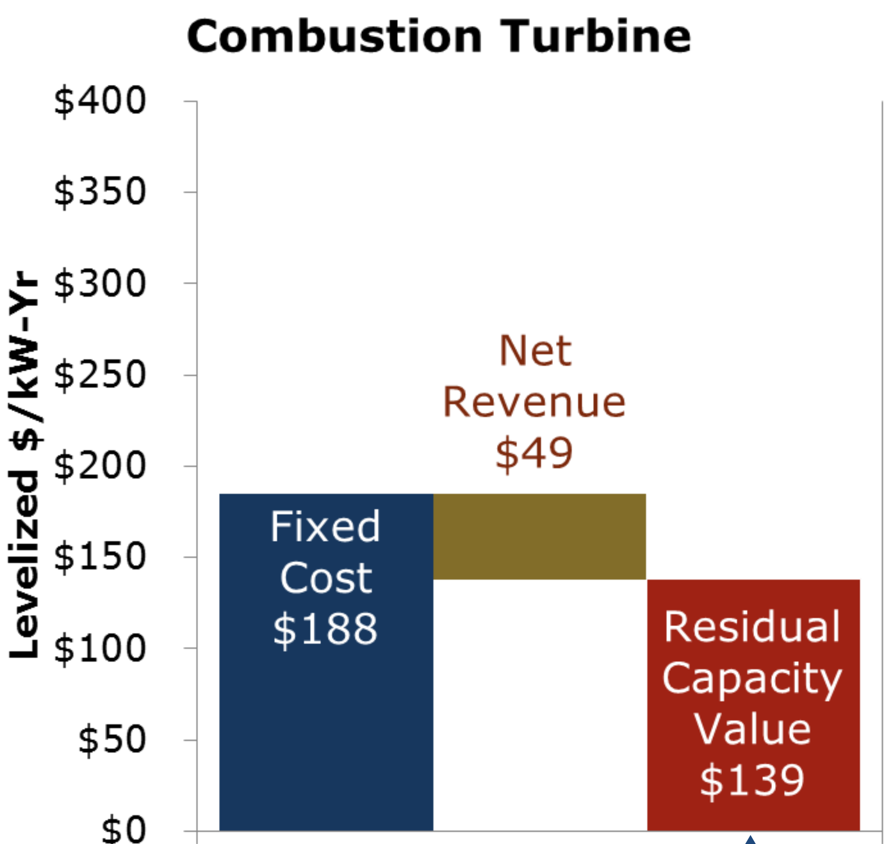
Playing the Markets

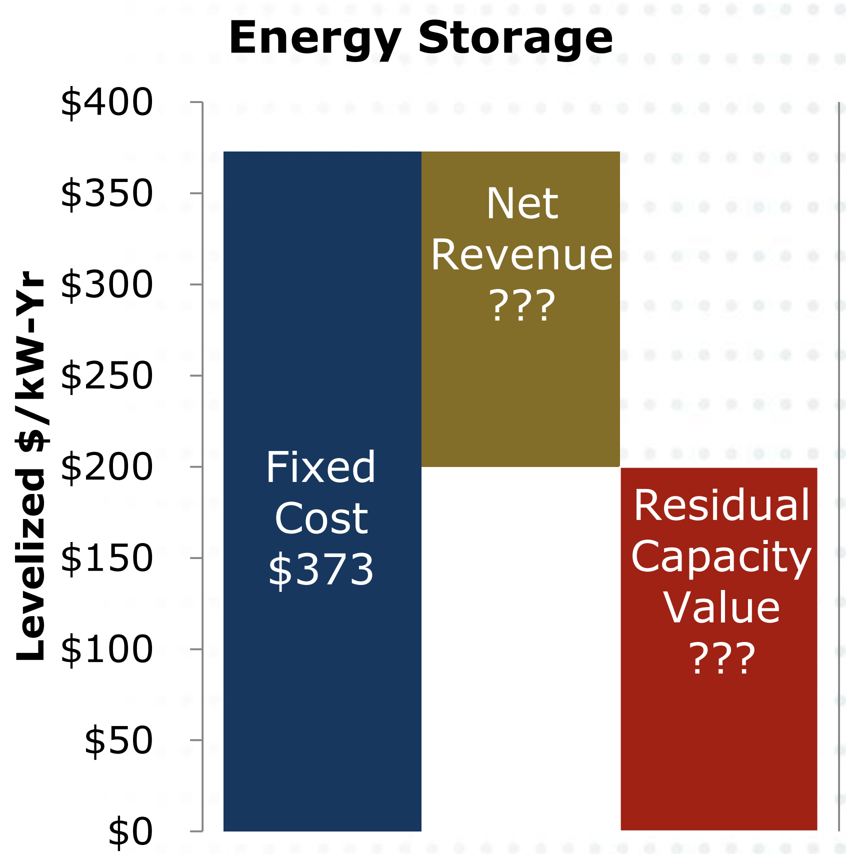




STORAGE – CT COMPARISON

Comparing Capacity Value



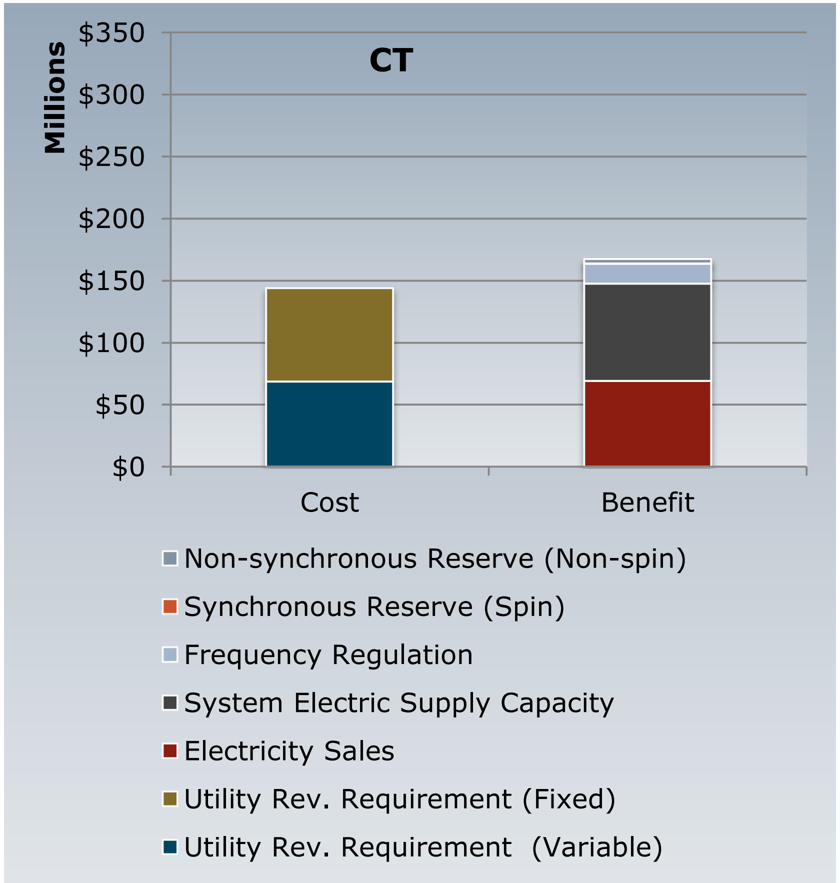


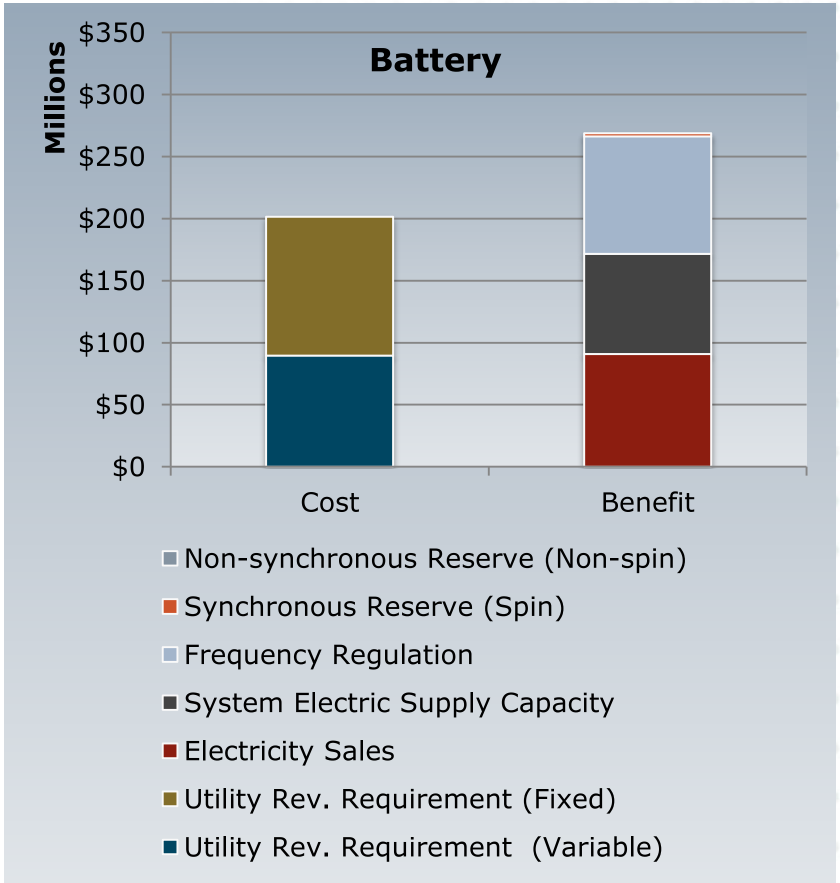
aka "CONE": Cost of New Entry

Storage – CT Comparison

Inputs (High Scenario)	Battery	CT
Installed Costs ($/kW)	**$2,000**	**$1,000**
Useful Life (Years)	**15**	**20**
Discharge Capacity (kW)	50,000	50,000
Discharge Duration (Hours)	**4**	**-**
Roundtrip Efficiency (%)/ Heat Rate (BTU/kWh)	**90%**	**9,300**
Variable O&M ($/MWh)	**$1.40**	**$5**
Energy ($/MWh)	$63.75	$63.75
Frequency Regulation Up ($/MW)	$9.76	$9.76
Frequency Regulation Down ($/MW)	$8.63	$8.63
Synchronous Reserves ($/MW)	$7.05	$7.05
Non-Synchronous Reserves ($/MW)	$1.04	$1.04
Resource Balance Year	2020	2020
Cost of New Entry ($/kW-Year)	$152	$152

Cost-Benefit Results

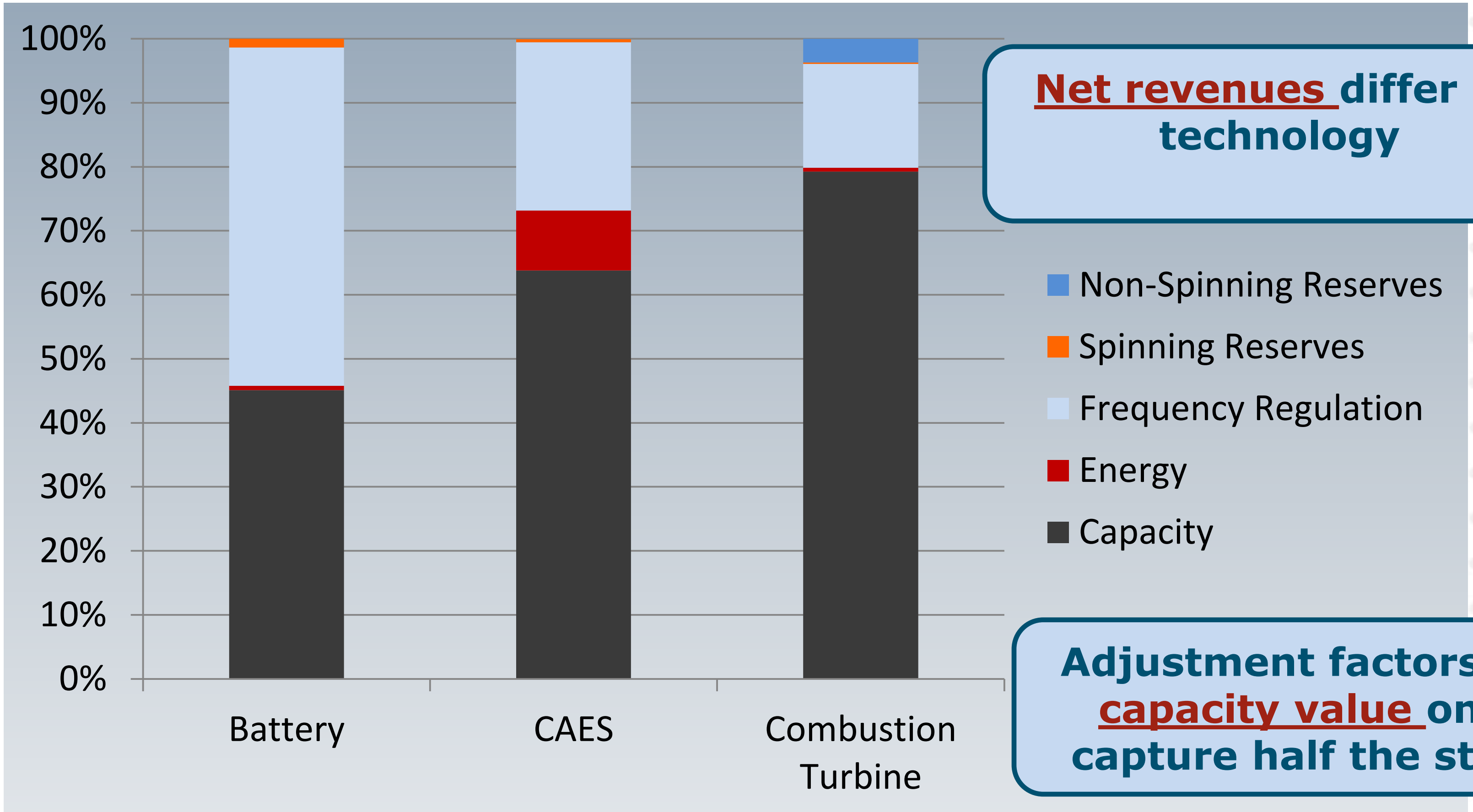




Storage has a higher utilization factor

And earns more revenues in energy and AS markets

Why Net Revenues Are Important



Net revenues differ by technology

Adjustment factors for capacity value only capture half the story

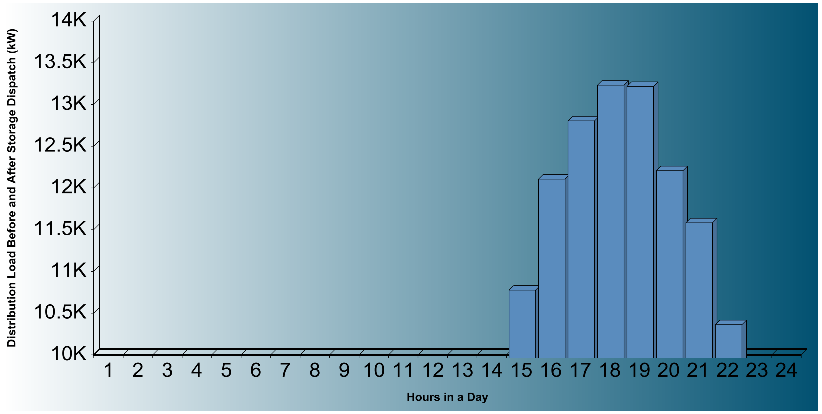
Capacity Factor	24%	21%	14%
Utilization Factor	132%	32%	22%

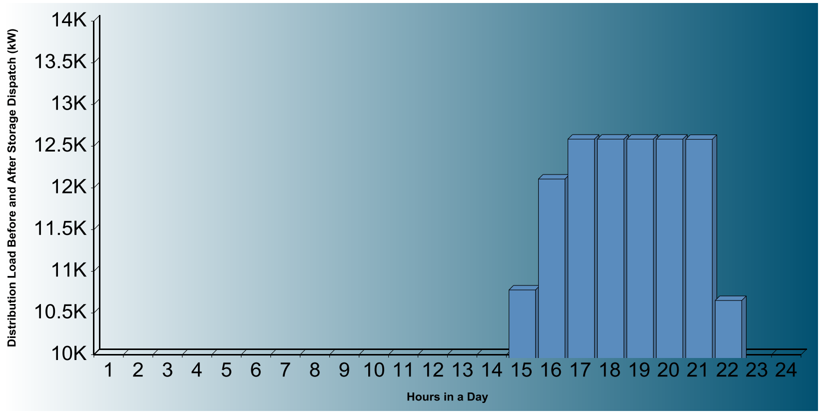
DISTRIBUTED STORAGE USE CASE

Distributed Storage Services

- Storage is placed behind distribution substation
- Storage dispatches to reduce substation load
- Dispatch is constrained by deferral obligations as well as substation load (i.e. can't charge near peak load or discharge when it would cause backflow)

Distribution Investment Deferral

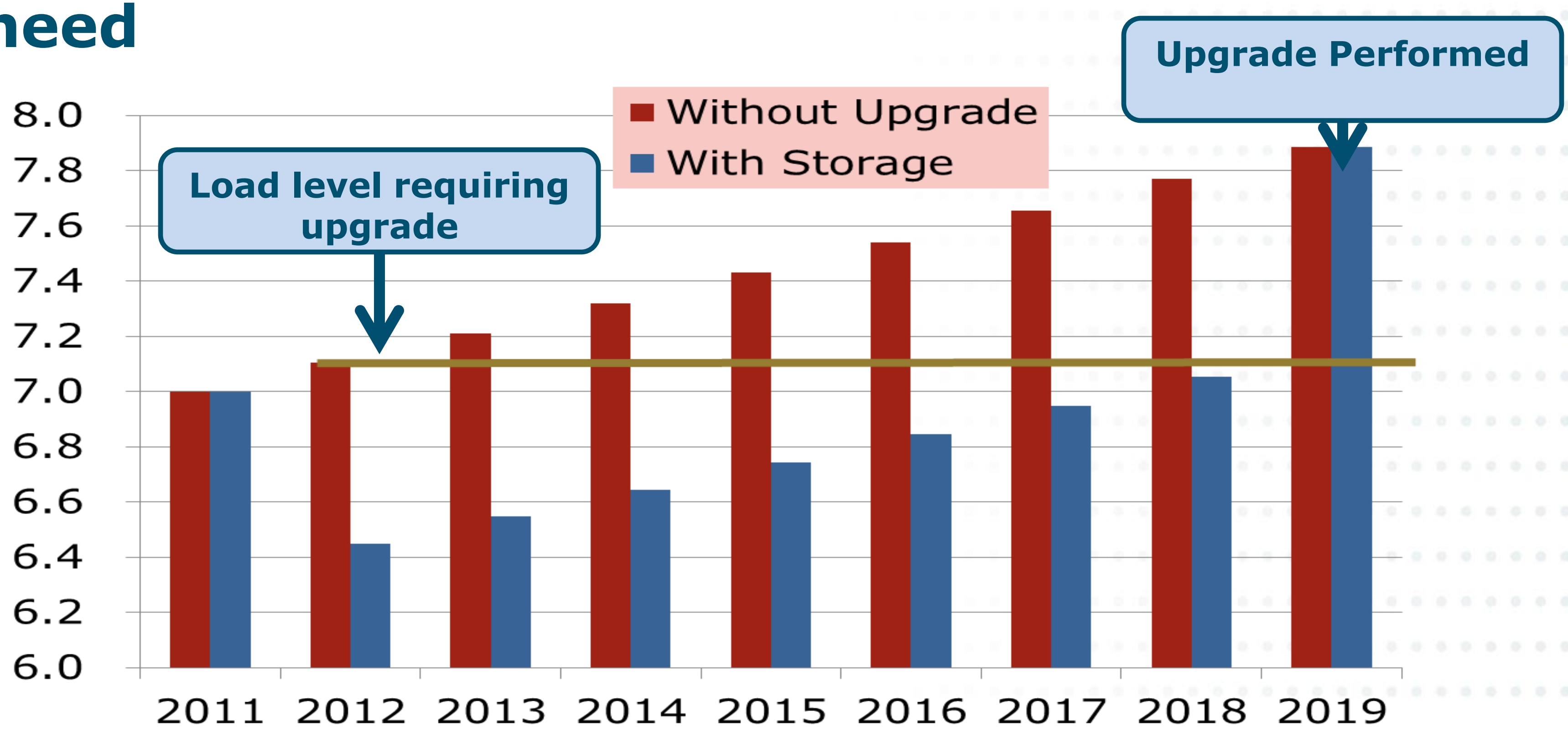




- **Storage is reserved on days with peak substation loads**
- **Storage dispatches against load to reduce peak**
- **Deferral Value**
  - **User Input**: $/kW-Yr. Value and years of deferral
  - **Calculated**: Enter feeder load shape, annual load growth and total cost of upgrade ($Million)

Distribution Deferral con't.

- Storage shifts feeder peak loads
- Upgrade is deferred until feeder loads with storage reach peak load level that triggered need



DISTRIBUTED STORAGE USE CASE SCENARIOS

Distribution Investment Deferral Inputs

Inputs	Low	High
Storage System Installed Costs ($/kWh)	$1,000	$500
Useful Life (Years)	15	15
Discharge Capacity (kW)	1000	1000
Discharge Duration (Hours)	4	4
Roundtrip Efficiency	90%	90%
Variable O&M ($/MWh)	$1.40	$1.40
Energy ($/MWh)	$63.75	$63.75
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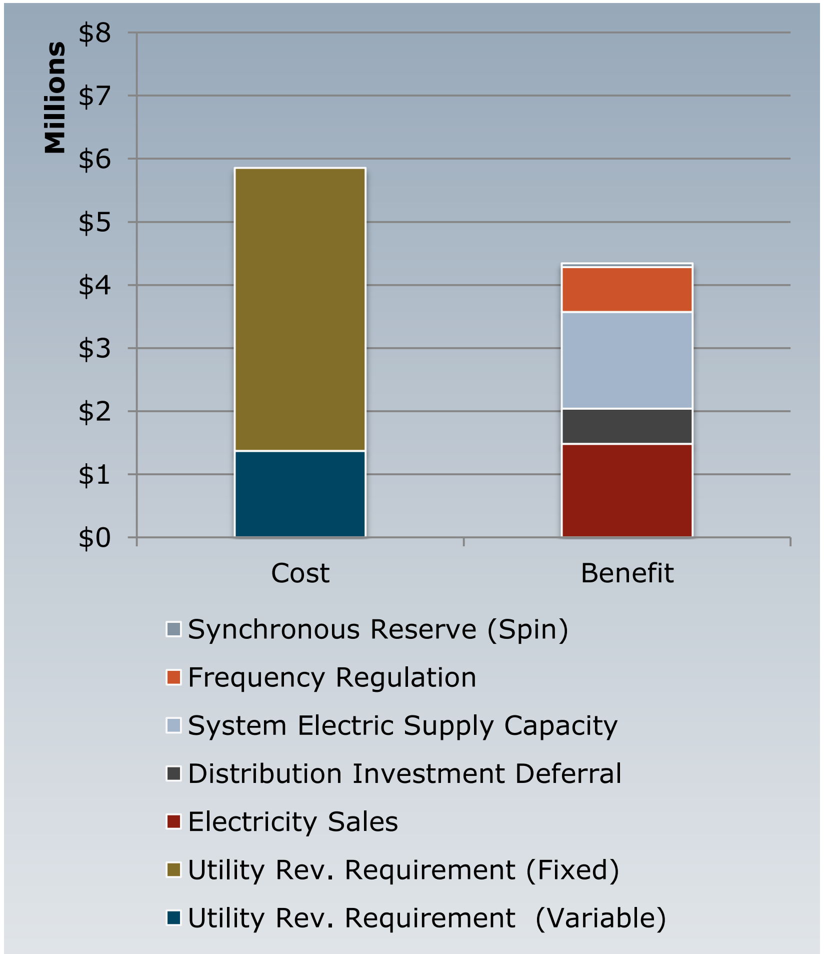
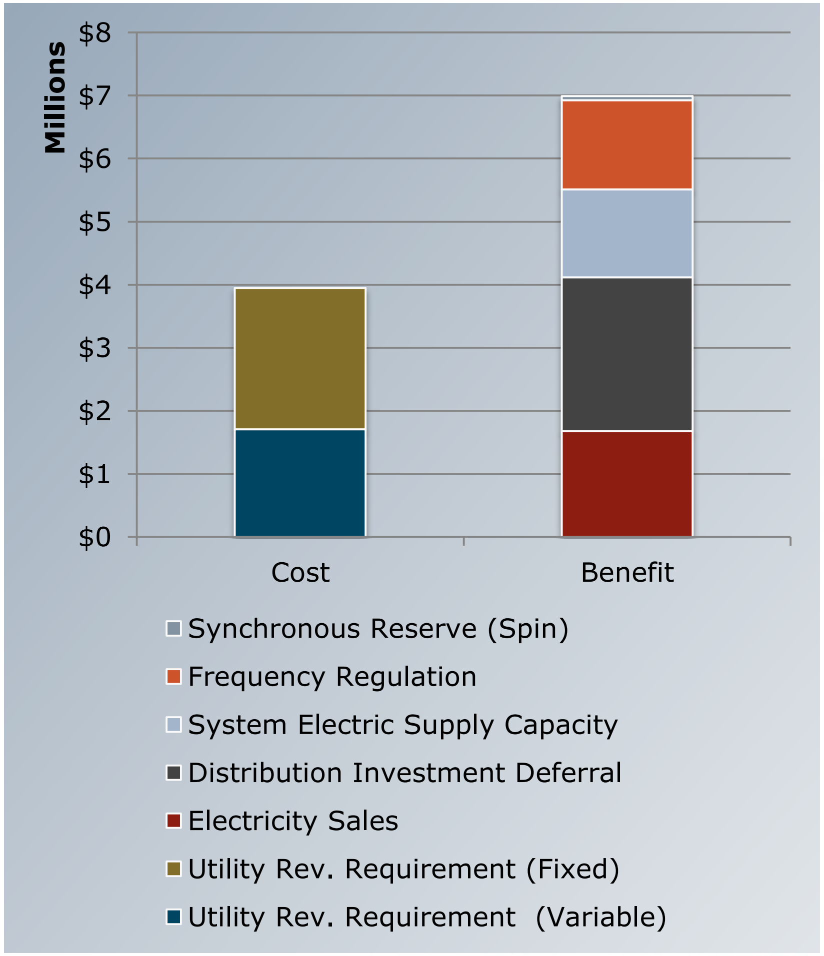
Resource Balance Year	**2025**	**2020**
Cost of New Entry ($/kW-Year)	$152	$152
Distribution Peak Load	12 MW	12 MW
Distribution Load Growth	**1.0%**	**0.5%**
Deferred Years (Calculated)	**5**	**9**
Distribution Investment CapEx	**$2.5M**	**$5.0M**

Distribution Investment Deferral Cost/Benefit Comparison





STORAGE IN RESOURCE PLANNING

The role of flexible resources

- **Quantity:** Procure sufficient capacity resources to meet target reserve margin and reliability targets

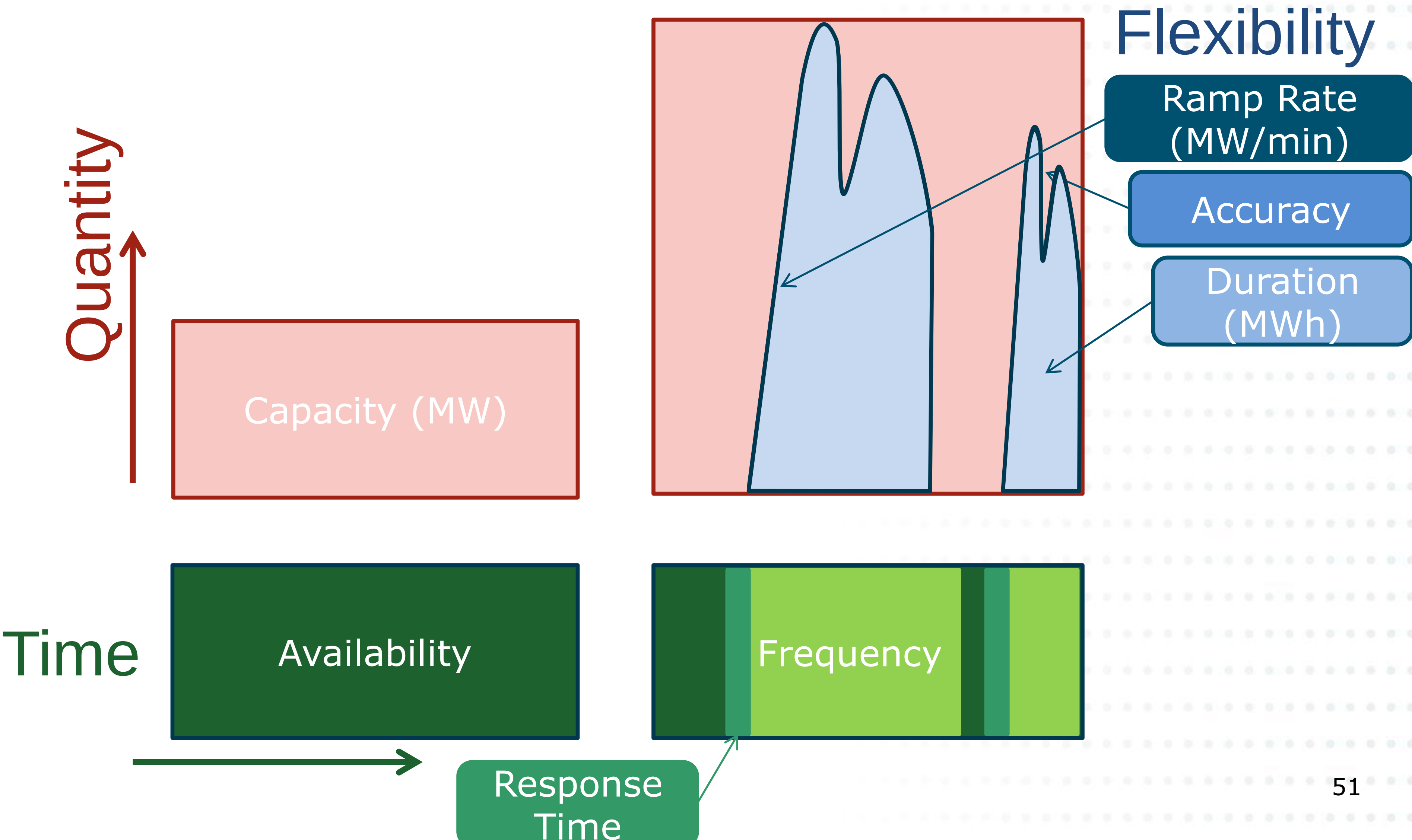
- **Flexibility:** Procure flexible capacity to meet short-term needs due to forecast error and variability in load and renewable generation

Evaluating Storage Within LTPP Planning Framework

LTPP			Storage OIR	
Step 0*	**Step 1**	**Step 2**	**Step 3**	**Step 4**
Variability Modeling	**Flexibility Need**	**Feasible Solutions**	**Production Simulation**	**Use-Case Modeling**
1 minute analysis of historical and simulated wind, solar and load data to quantify variability and forecast error	Define technology neutral resource needs and performance attributes to meet reliability targets	Identify and define feasible flexible resources, including storage use-cases, to meet identified needs	Define limited number of 33% RPS compliant scenarios including flexible resources to model in production simulation	More detailed modeling of costs and revenues for defined storage applications providing multiple services

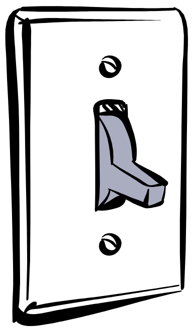
* Step 0-2 terminology borrowed from 2010 LTPP proceeding

Characterizing a Resource



What is the Best Solution to Satisfy Need?

Flip a switch



- **Operational changes can mitigate flexibility shortfalls**
  - Reserve scheduling, “pre-curtailment” of renewables

Grab a shovel

- **Steel in the ground can help to meet both capacity and flexibility requirements**
  - Fast, expensive resources vs. cheaper, slower ones

- **A useful model will be able to quantify the trade-offs between these options**
  - What measure or combination of measures satisfies need?

There Are Several Flexible Resource Alternatives

- **Re-dispatch:** of existing resources: e.g. dispatch more fossil plants at partial load with presumed increase in production costs
- **Curtailment:** limited number of curtailments of renewables and/or load could address most extreme events
- **Scheduling/Forecasting:** improved processes for forecasting net load and scheduling resources
- **New Markets:** new market products such as ramp, load following and load participation
- **Upgrades:** enhancement of existing resources
- **Grid Resiliency:** augment grid infrastructure for more resiliency in face of variability
- **New Resources:** new flexible and responsive generation or non-generation resources

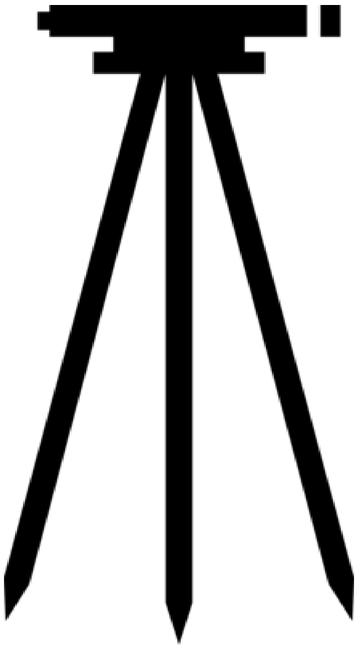
The "Sledgehammer" Approach: Stochastic Production Simulation

- **Minutely time step resolution**
- **Monte Carlo for forecast errors**
- **Requires large datasets**
  - Detailed load, wind, solar datasets
  - Individual unit specifications
  - Scheduled and forced outages
  - Hydro and import conditions

Challenges

- **Run time: full stochastic simulation may be impractical**
- **Year-long simulation may not be able to capture long-term uncertainties, important for planning analysis**
- **Flexibility of system depends on chosen reserve requirements – possibility of "false violation"**
- **Difficult to incorporate expansion decision**

One Path Forward: Reduced-Form Production Simulation Modeling



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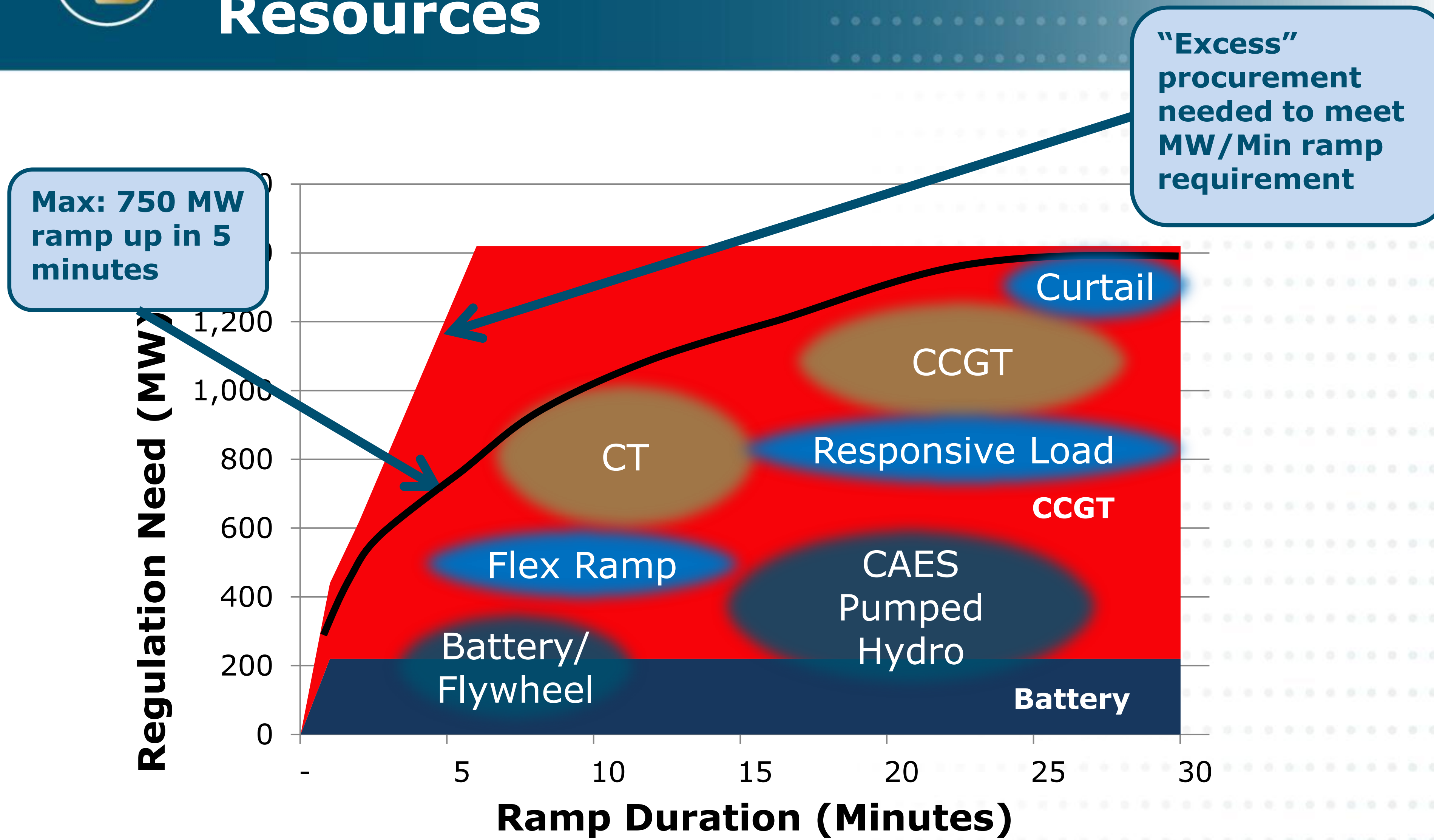
+ **Three key modifications to production simulation modeling framework:**
  1. **Stochastic operations:** Run thousands of draws of a single day per month to accurately characterize long-term uncertainty
     - Preserve time-sequential unit commitment and operations over 24 hours
  2. **Endogenous reserves:** Include endogenous, minutely specification of reserve flexibility requirements to avoid false violations and accurately characterize fast-ramping resource
  3. **Expansion decisions:** Incorporate operational and expansion decisions (with fixed costs) to find optimal solutions
+ **Requires elimination of *all* detail that doesn't help answer question at hand in order to minimize run time**

Portfolio Analysis of Flexible Resources



Do Not Cite - For Illustrative Purposes Only

Need → Portfolio→ Cost/Benefit

Planning Framework

Step 0	Step 1	Step 2	Step 3	Step 4
Variability Modeling	Flexibility Need	Feasible Solutions	Production Simulation	Use-Case Modeling

Storage Analysis Framework

- Step 1: Grid Need/ Solution Concepts
  - Step 1a: Grid Service Requirements
- Step 2: Feasible Storage Use Cases
- Step 3: Grid Impacts and Additional Benefits
- Step 4: Energy Storage Business Cases

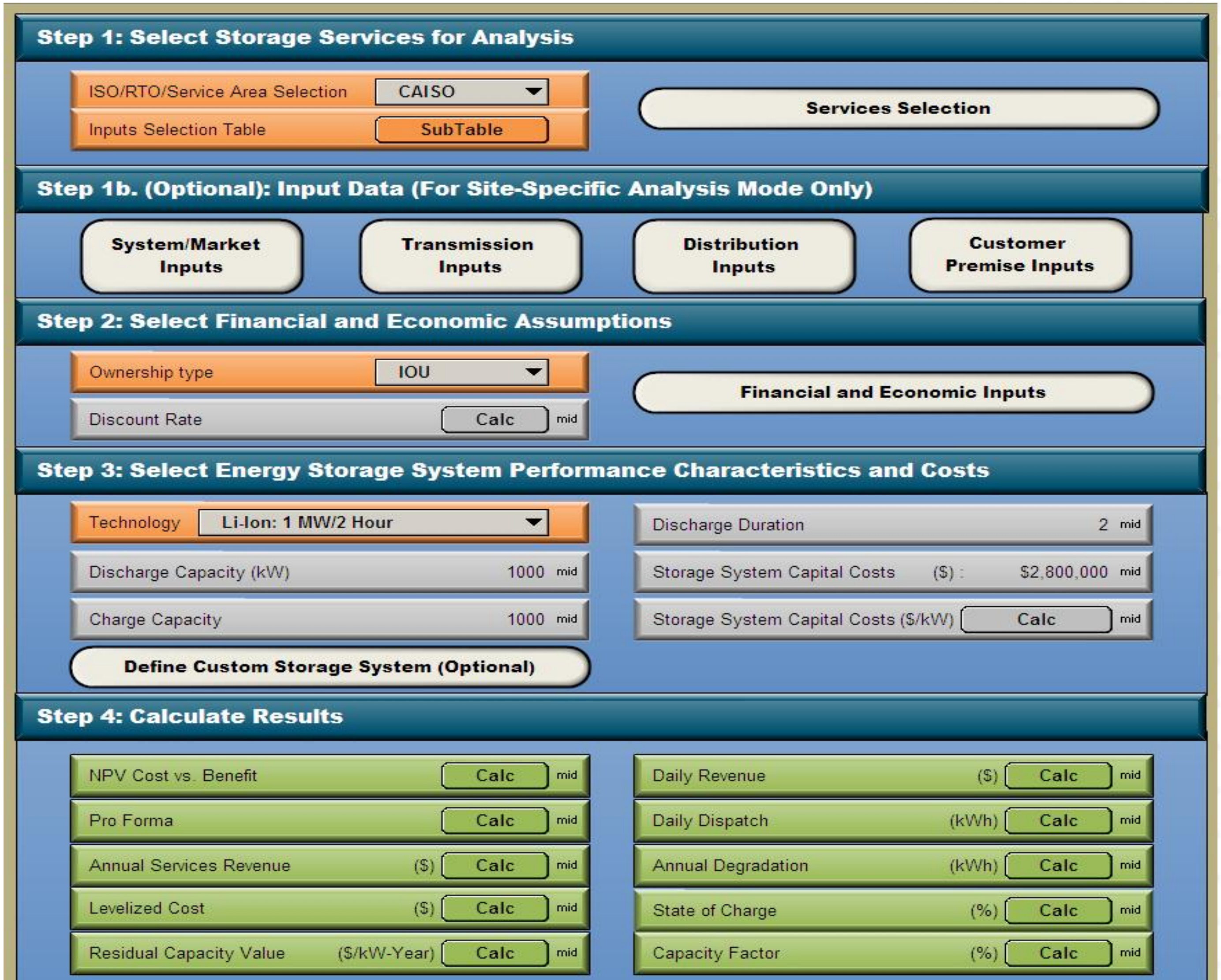
CONCLUSIONS

Conclusions

- Time to move discussion from **what** storage can do to **how** to quantify value
- *Specific* definitions of grid needs paired with storage use cases
- Rigorous analysis of energy storage ***with uncertainty*** is possible
- Need →Portfolio → Cost Effectiveness
- Prioritize analysis: eliminate all non-essential detail

APPENDIX SLIDES

ESVT SCREEN INPUTS & OUTPUTS


Step 1: Select Storage Services for Analysis
ISO/RTO/Service Area Selection
CAISO
Inputs Selection Table
SubTable
Services Selection
Step 1b. (Optional): Input Data (For Site-Specific Analysis Mode Only)
System/Market Inputs
Transmission Inputs
Distribution Inputs
Customer Premise Inputs
Step 2: Select Financial and Economic Assumptions
Ownership type
IOU
Discount Rate
Calc
mid
Financial and Economic Inputs
Step 3: Select Energy Storage System Performance Characteristics and Costs
Technology
Li-Ion: 1 MW/2 Hour
Discharge Capacity (kW) 1000 mid
Charge Capacity 1000 mid
Define Custom Storage System (Optional)
Discharge Duration 2 mid
Storage System Capital Costs ($) : $2,800,000 mid
Storage System Capital Costs ($/kW) Calc mid
Step 4: Calculate Results
NPV Cost vs. Benefit Calc mid
Pro Forma Calc mid
Annual Services Revenue ($) Calc mid
Levelized Cost ($) Calc mid
Residual Capacity Value ($/kW-Year) Calc mid
Daily Revenue ($) Calc mid
Daily Dispatch (kWh) Calc mid
Annual Degradation (kWh) Calc mid
State of Charge (%) Calc mid
Capacity Factor (%) Calc mid

Select Services

Main Page

System/Market Services

- [x] System Electric Supply Capacity
- [ ] Local Electric Supply Capacity
- [x] Electric Energy Time-Shift (Arbitrage)
- [x] Frequency Regulation
- [x] Synchronous Reserve (Spin)
- [ ] Non-synchronous Reserve (Non-spin)
- [ ] Black Start

Transmission Services

- [ ] Transmission Investment Deferral
- [ ] Transmission Voltage Support

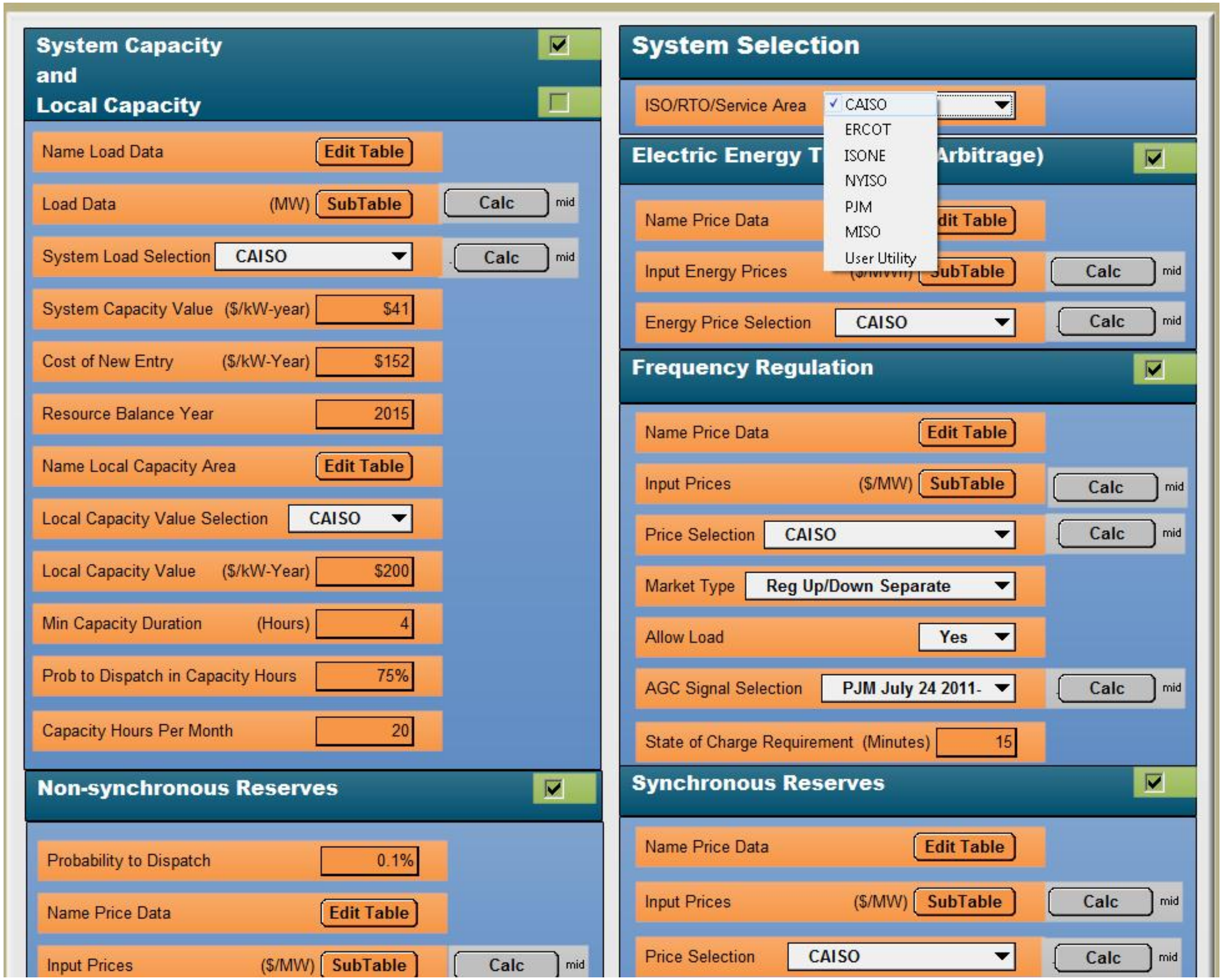
Customer Premise Services

- [ ] Power Quality
- [ ] Power Reliability
- [ ] Retail TOU Energy Time-Shift
- [ ] Retail Demand Charge Management
- [ ] Microgrid Reliability
- [ ] PV Ramp Rate Smoothing

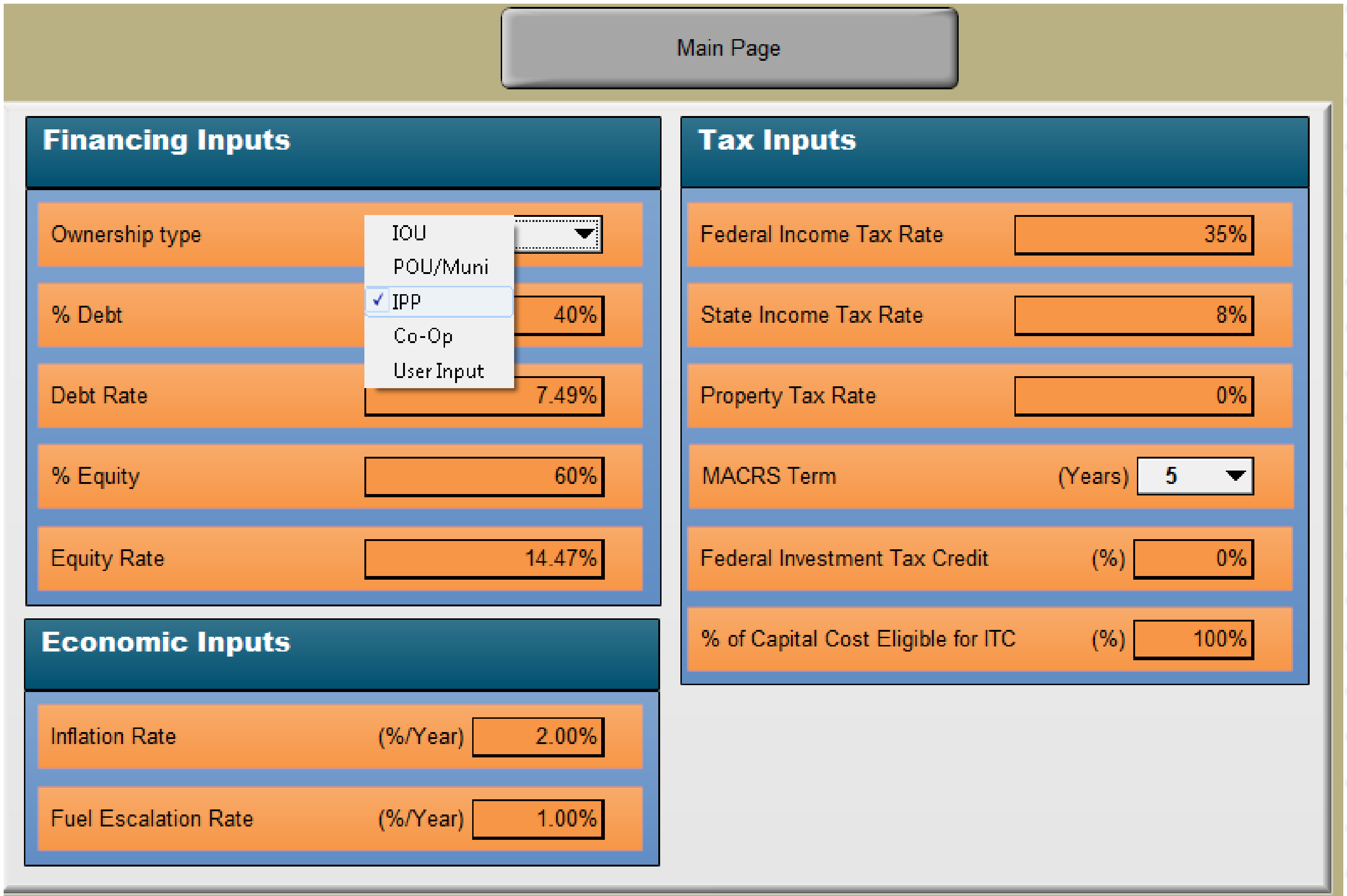
Distribution Services

- [ ] Distribution Investment Deferral
- [ ] Distribution Losses Reduction
- [ ] Distribution Voltage Support

Market Price Inputs



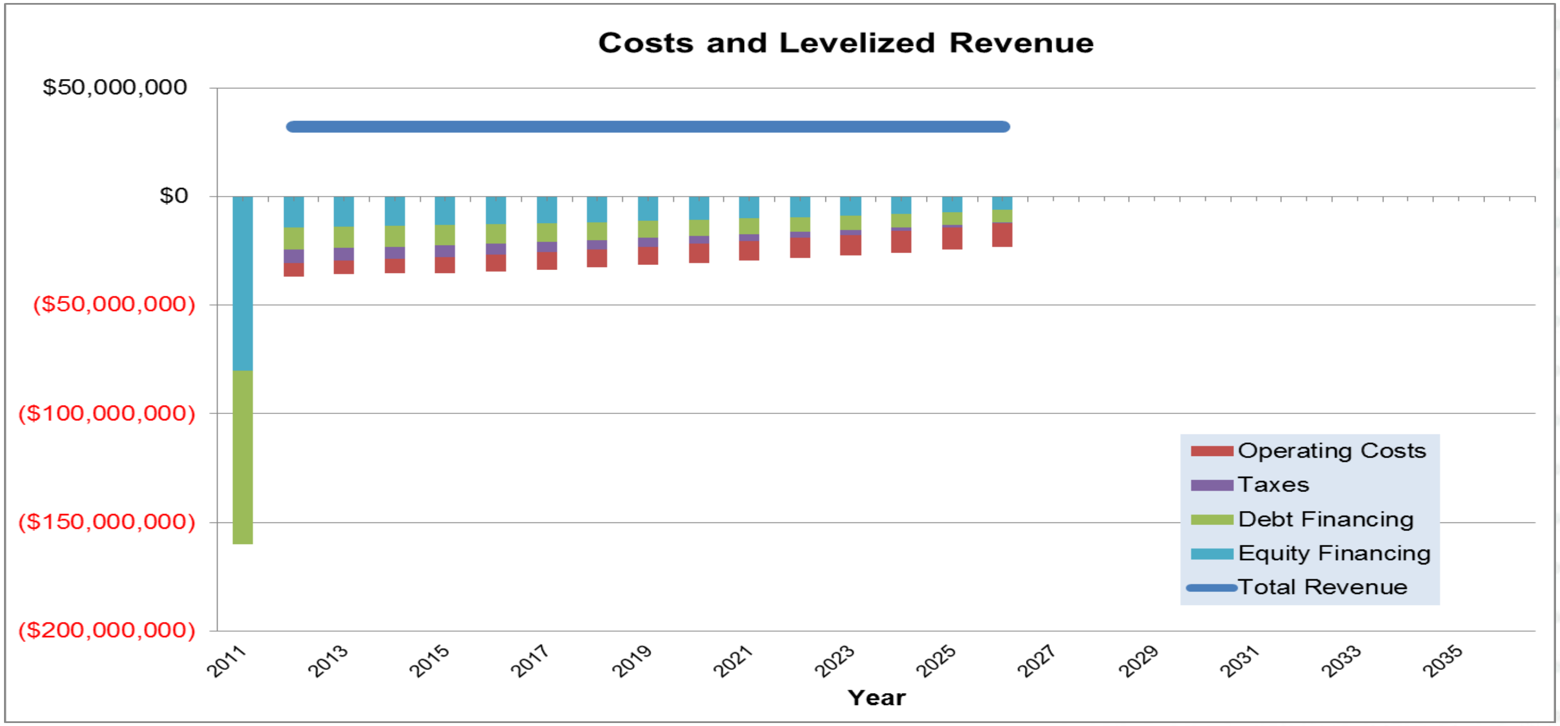
Financial Inputs



Pro-Forma Cash Flow

IOU/POU REVENUE REQUIREMENT MODEL	2011	2012	2013
Usable Storage		300,000	300,000
Cycles		365	365
Energy Production (kWh)		**109,500,000**	**109,500,000**
Total Revenue		**$36,699,178**	**$35,786,439**
Operating Costs			
Charging Costs		($4,380,000)	($4,599,000)
Fuel Costs		$0	$0
CO2 Costs		$0	$0
Periodic Maintenance		$0	$0
Fixed O&M Costs		($224,580)	($229,072)
Variable O&M Cost		($50,000)	($51,000)
Insurance Costs		($767,654)	($783,007)
Property tax		($800,694)	($760,659)
Excise tax		$0	$0
Payment-In-Lieu-Of-Taxes (PILOT) - ($/kW)		$0	$0
Payment-In-Lieu-Of-Taxes (PILOT) - ($/MWh)		$0	$0
Royalty payment to landowner		($71,498)	($71,498)
Gross-receipts tax		$0	$0
Total Costs		**($6,294,425)**	**($6,494,235)**
Operating Profit		**$30,404,753**	**$29,292,204**
Revenue Requirement			
Operating Costs		$6,294,425	$6,494,235
Net Debt Financing Costs		$4,804,161	$4,483,884
Equity Return		$8,843,468	$8,374,016
Depreciation		$10,675,914	$10,675,914
Tax on Equity Return - before grossup		$3,603,360	$3,412,076
ITC		$0	$0
PTC		$0	$0
Tax Grossup		$2,477,849	$2,346,314
Total Revenue Requirement		**$36,699,178**	**$35,786,439**

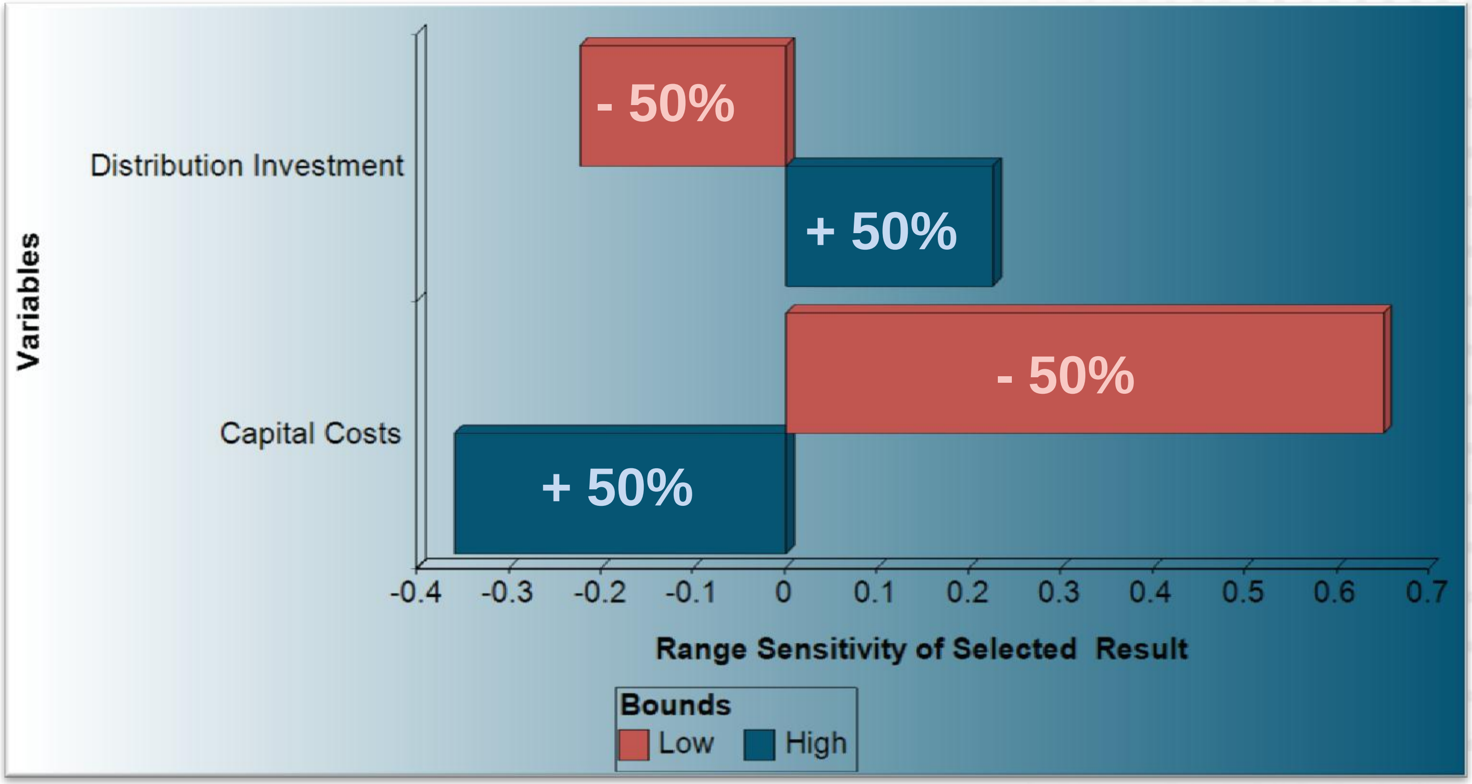
Levelized Costs



	Total		Levelized		Present Value	
	Sum ($)	NPV	$/MWh	$/KW-yr	PV $/kW	PV $/kWh
Fixed Costs	$368,720,593	$234,298,958	$239.40	$524.29	$4,686	$781
Variable Costs	$95,378,779	$53,345,943	$54.51	$119.37	$1,067	$178
Total Costs	**$464,099,373**	**$287,644,901**	**$293.91**	**$643.66**	**$5,753**	**$959**

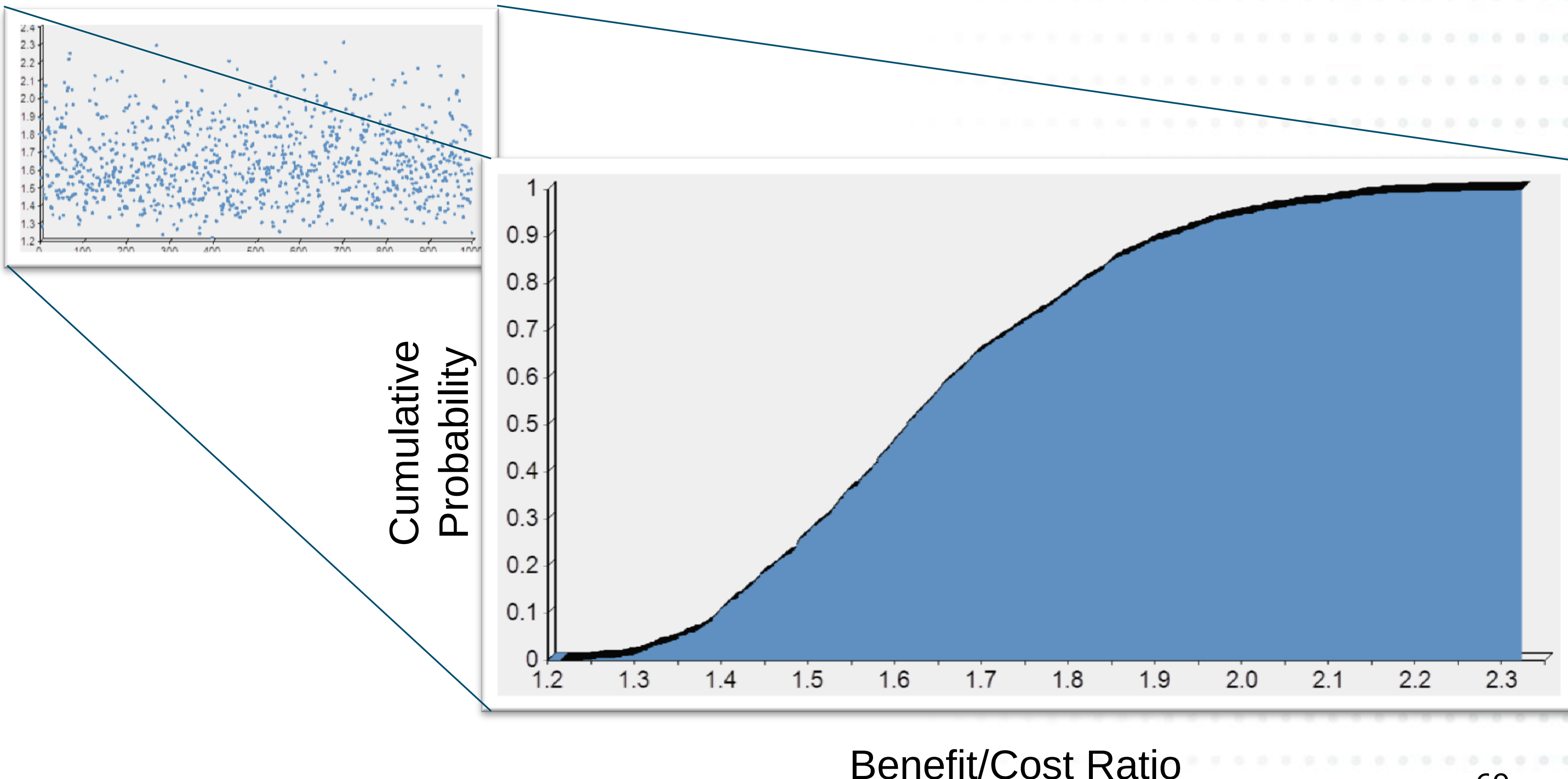
Sensitivity

Capital Cost Uncertainty: +/- 50%
Distribution Investment Cost Uncertainty: +/-50%



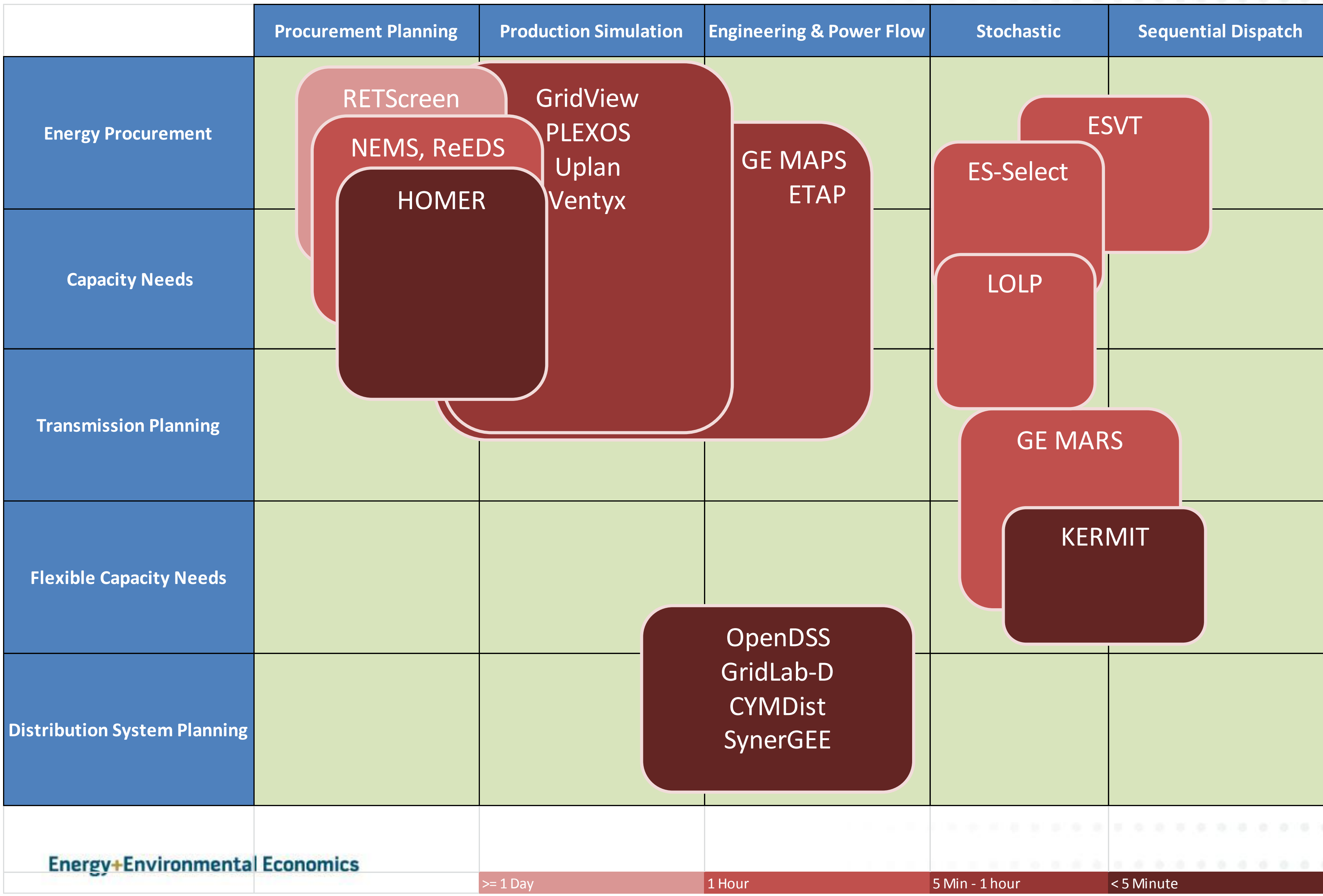
Monte Carlo

Capital Cost Uncertainty: +/- 50%
Distribution Investment Cost Uncertainty: +/-50%

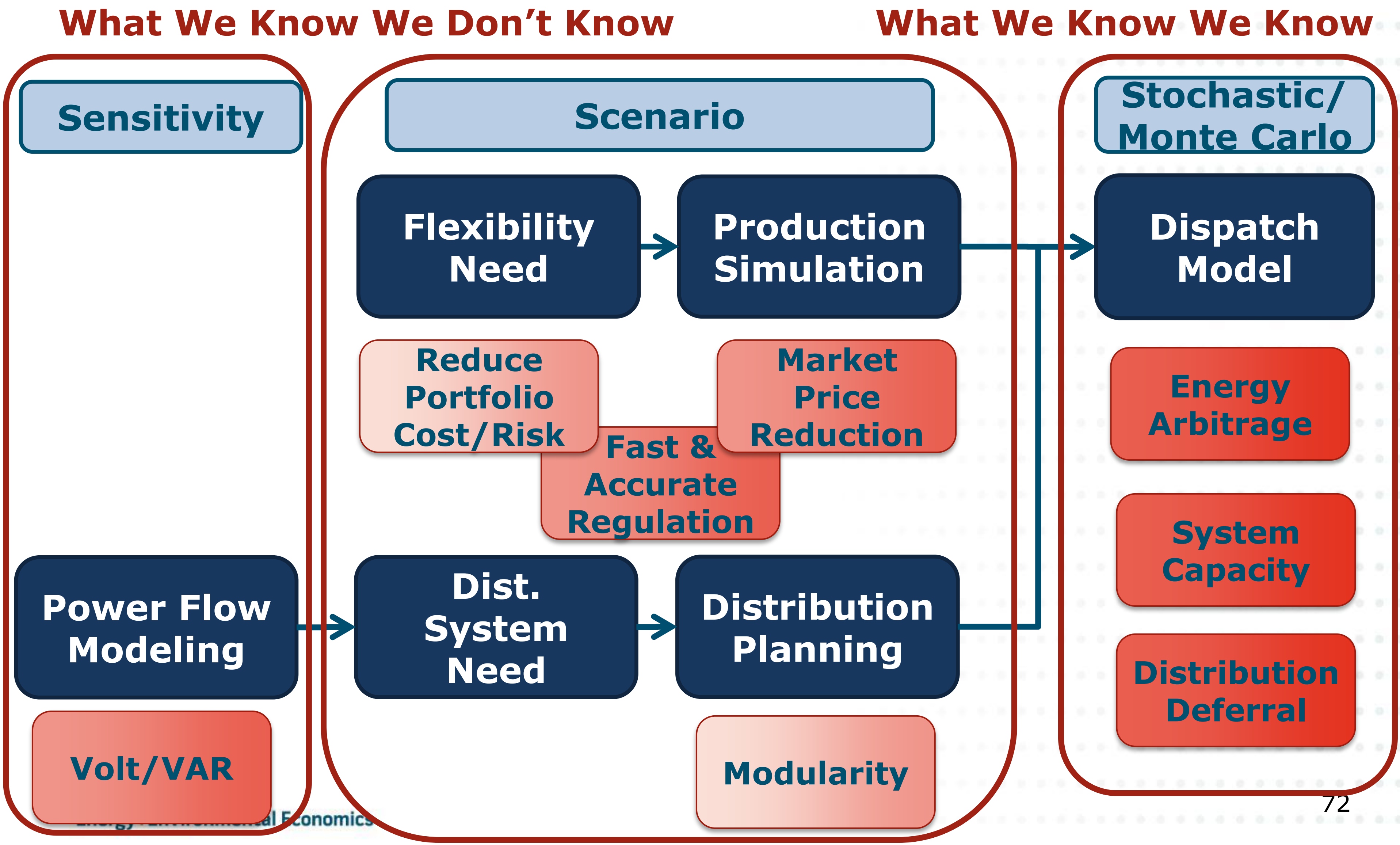


MODELS

Matrix of Energy Storage Modeling Tools



Modeling Uncertainty



BENEFIT MATRIX

Benefit Matrix 1

	Storage Benefits						Relative Importance of		
	Customer	Distribution	Transmission	Generation	Renewable Integration	Description	Speed of Response	Duration	Efficiency
Planning & Procurement		Reduced infrastructure requirements	Reduced procurement of Ancillary Services	Reduced need for system and/or flexible capacity		Having more flexible and responsive resources reduces the size of distribution equipment, total quantity of ancillary services and total quantity of sytem capacity that is required to meet reliability targets given uncertainty and forecast error.			
Reliability	Improve Customer Reliability/Back-up Power	Distribution Investment Deferral (Reliability)	Reduce NERC N-1 Contingency	Reduce LOLP		Storage remains full throughout year to provide backup power during outage			
Capacity		Distribution Investment Deferral (Capacity)	Transmission Investment Deferral	System or Local Generation Capacity	Renewable Firming (Increase NQC/ELCC)	Available to provide energy if called upon during peak load hours (e.g. Planning Reserve Margin). Subject to meeting minimum energy delivery requirements per utility or capacity market rules. Aka Resource Adequacy (RA), Local Capacity Resource (LCR), Planning Reserve Margin (PRM)			
	Demand Charge Reduction		Transmission Access Charge Reduction						
				Flexible Capacity		Provide a "flexible" capacity resource to meet identified need for flexible resources (as opposed to capacity required for peak loads)			
	Option value (Modularity)					Modular (and transportable) storage provides flexibility to defer large, lumpy investments in new capacity and to delay decision making with uncertainty to determine if anticipated needs actually materialize (e.g. forecasted load growth).			
Time Shfit	TOU Energy Charge Reduction	Distribution Peak Shaving	Reduce Transmission Congestion	Wholesale Time Shift/Arbitrage	Renewable Generation Time Shift	Reduce loads/discharge during high price/load hours and increase loads/charge during low price/load hours			
	Option value (Volatility)					Storage provides a call/put option which gives the owner the choice, but not the obligation to sell or buy energy. In addition to the value of trading on 'expected' prices (intrinsic value), storage provides the owner an option (extrinsic) value driven by the uncertainty or volatility in market prices or quantities			

Benefit Matrix 2

	Storage Benefits						Relative Importance of		
	Customer	Distribution	Transmission	Generation	Renewable Integration	Description	Speed of Response	Duration	Efficiency
Generation Operation		Backflow Prevention			Overgeneration	absorb excess generation when baseload, non-dispatchable and renewable generation exceeds load (typically at night, but also possible during morning and evening ramp). Absorb excess generation on the distribution system to prevent backflow.			
				Unit Commitment/Start Up Cost Reduction		Reduce the number and MW of flexible generation units that must be started up and operated to provide sufficient ramp and reserve capability			
				Efficiency Improvement/ Emissions Reduction		Dispatch storage to reduce ramp rates for generators to maximize their efficiency			
				Market Price Effect/Reduce Production Cost		Reduce overall cost of energy production (including unit commitment and efficiency improvements) and market clearing price.			
Transmission & Distribution Operations		O&M Reduction/Equipment Life Extension				reduce switching or thermal loading on T&D equipment so as to reduce O&M and extend life			
		Loss Reduction				Shift loads to reduce the overall power losses (Ohmic losses are proportional to the square of the current on the line). Storage can also reduce line losses by using the inverter to correct for a low power factor on the distribution network.			
		Voltage Support			Renewable Power Smoothing	Provide both real and reactive power to the distribution circuit to raise voltage . Boosting voltage at the end of distribution feeders can improve power quality as well as provide conservation voltage reduction (CVR). Also smooth rapid fluctuations in PV output that can occur with cloud cover and cause volt and VAR fluctuations on the distribution system.			
	Customer Power Factor Improvement	VAR Support			Renewable Generation Power Factor Improvement	Use inverter to dynamically provide reactive power, resulting in a number of benefits. Properly controlled, inverters can filter harmonics, reduce flicker, improve voltage sag and undervoltage, and reduce line losses.			
	Improve Customer Power Quality	Distribution Investment Deferral (Power Quality)				Reduce momentary outages, voltage & current sags/swells, harmonics and other power disturbances			

Benefit Matrix 3

	Storage Benefit: Ancillary Service	Description	Relative Importance of: Speed of Response	Duration	Efficiency
Operating Ancillary Services	Inertial Frequency Response	inherent in the system due to rotating characteristic of typical Load (motor, pumps etc.) and conventional generation (synchronous generators). The Inertial Frequency Response provides counter response within seconds to arrest the frequency deviation. System inertia can be defined as the total amount of kinetic energy stored in all spinning turbines and rotors in the system. Can also be provided by fast responding storage systems.			
	Primary Frequency Response	the instantaneous proportional increase or decrease in real power output provided by a Generation Resource in response to system frequency deviations. This response is in the direction that stabilizes frequency. Primary Frequency Response is attained due to Governor or Governor- like action to instantly act relative to the frequency deviation. The Primary Frequency Response is generally delivered completely within 14 seconds.			
	Fast/Accurate Frequency Regulation	Provide AGC frequency regulation in AS markets that is faster and more accurate than traditional generation resources			
	Frequency Regulation	executed by Automatic Generation Control (AGC) . The AGC system deploys regulating reserves to restore the frequency closer to scheduled frequency. Generally the AGC action can take anywhere from seconds to minutes depending on the resource			
	Real-Time/Balancing Energy	Energy dispatched directed by the grid operator every 5-10 minutes to balance load and generation within the hour			
	Ramp (~5 min - 1 hr)	ability to rapidly increase or decrease output (measured in MW/Min) to manage uncertainty and forecast error for generation and load			
	Load Following	balancing load and generation in the 5-30 minute time frame (between 5 minute imbalance energy and hourly real-time energy markets)			
	Hour to Hour Ramp (> 1hr)	Increase generation over 3 hours in the morning to match increasing loads and reduce generation in the late evening as loads decline. Also required to match fairly predictable increases and decreases in wind and solar generation between evening and daytime periods.			

Benefit Matrix 4

	Storage Benefit		Relative Importance of		
	Ancillary Service	Description	Speed of Response	Duration	Efficiency
Contingency Reserves	Sync/Spinning Reserve	Generation (or responsive load) that is ready to respond immediately, in case a generator or transmission line fails unexpectedly. Spinning reserve begins to respond immediately and must fully respond within ten minutes (or potentially 15 minutes according to the revised NERC DCS requirement). ISO rules differ on whether 10 minute reserves must be synchronized to the grid			
	Non-spinning Reserve	Similar to spinning reserve, except that the resource is not necessarily required to be synchronized to the grid and the response does not need to begin immediately. Full response is generally required within 10 to 30 minutes.			
	Replacement Reserve	An additional reserve required in some regions. It begins responding in 30 to 60 minutes.			
	Variable Generation Tail Event	Reserves that are available to cover infrequent, but large ramps of variable generation. The difference is that large variable generation ramping events are typically slower than conventional contingencies. While a conventional contingency happens instantly, a large variable energy resource ramp will typically take two hours or longer for the full ramp. NERC reliability rules require contingency reserves to be restored within 90 minutes, making most variable generation tail events too slow to effectively use conventional contingency reserves. A reserve that is able to maintain response for two hours or longer may be required to respond to large, infrequent variable energy resource ramps.			
	Black Start	Black start service is the ability of a generating unit to start without an outside electrical supply, or is the demonstrated ability of a generating unit with a high operating factor to automatically remain operating at reduced levels when disconnected from the grid. Black start service is necessary to help ensure the reliable restoration of the grid following a blackout.			